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Editorial

Aftermath

"Ask yourself this question… Would I want my child to repeat my actions of today?"

Paul D Cummings

It's been one year since the horror and tragedy of September 11, 2001, and the ripples and repercussions continue to spread. We have seen a nation united in grief and outrage provide an outpouring of love and support as families, friends and loved ones mourned, innocent victims were laid to rest and heroes were honored personally and posthumously. The civilized countries of the world have rallied to assist our government and military in bringing the perpetrators to justice while engaging in a worldwide battle against terrorism. Rubble has been cleared and plans have been offered for rebuilding and renewal, but the scars in the hearts and minds of so many are indelible. For most, innocence has been shattered and the saying that "time heals all wounds" sounds clichéd and trite when applied to the impact of this atrocity on the lives of the American people.

Yet as I write this editorial, I am painfully aware of slowly being distanced from the reality of the event. Of course, I still feel the sense of shock when viewing replays of the destruction of the Trade Center, the sting of tears at descriptions of personal loss and the swell of pride in the documented acts of selflessness and heroism demonstrated by so many individuals. However, life does go on, and the millions of printed words and countless hours of television coverage have begun to produce a gradual numbing of emotions. I pray that this is only a protective response to the pain and horror and that we will never treat "9-11" as a simple piece of history that is easily forgotten or even denied by some. The lessons learned from the Holocaust should be remembered. Perhaps it is an appropriate time for thoughtful introspection and re-evaluation of the impact of these acts of terrorism on our families, our daily lives, our goals and our plans and dreams for the future. My family and I have tried to do this and would like to share our thoughts with you.

Fear. There is no denying that this terrorist goal is easily realized by acts of violence against random innocents. We are forcefully reminded of how fragile life really is and how easily it can be taken. Fear is always the first reaction. When will it happen again? Where can I be safe? How can I protect my loved ones? Should I run, hide or fight? This kind of fear can either innervate or immobilize. With reason, it can make us stronger. Uncontrolled, it can incapacitate us and rob us of our existence. Either way, it is rarely forgotten. My family is trying to use our fear to strengthen our faith and our determination to live our lives as positively and productively as possible. Community involvement and sharing with others less fortunate has taken on new meaning. We have gained an increased appreciation for time spent together and the quality of that interaction. We listen to each other more and share our thoughts and experiences. Simple family activities have assumed much greater importance, and we no longer take for granted that we can always express our love and feelings tomorrow or the next day. Daily hugs have become the norm.

Fear frequently engenders anger and suspicion, particularly toward those who are strangers or "different." It is human to seek an enemy to blame, a face or group to vilify and punish. Such responses, while natural, often result in overreaction and generalization. Guilt judged by appearance alone. One of my personal fears was that September 11th would create a backlash against Americans of different ethnic, cultural or religious backgrounds… a resurgence of the Japanese interment compounds of World War II. This would be tragic since the very foundation of America and our democratic way of life is based on diversity and freedom from persecution. My family feels that we must try to be citizens of the world and remember to look at ourselves in that context. Seeing ourselves as others see us was made very clear to me shortly after "9-11" when some of the residents in my Graduate program, who are from Middle Eastern countries, were being pressured by their parents to come home because they feared for their safety in the United States. The press and media in those countries were painting a bleak picture of hate and persecution of foreign nationals in the US. I was both humbled and gratified when my students explained that most Americans were not like that and that their instructors and colleagues treated them with respect, courtesy and friendship and that they wanted to stay. Isolationism is not an answer to terrorist threats, but only strengthens the divisiveness they want to exploit.

Over time, fear, anger and suspicion leave us with feelings of uncertainty and doubt. This has been evident in increased security measures, travel restrictions and economic downslides. Today, concerns over disappearing savings, investments and retirement funds are front-page news and share space with accusations and "finger pointing" related to dissatisfaction with government agencies and their management of events leading up to and following September 11th. While such reactions are certainly understandable, we often forget how fortunate we are to be able to express these opinions openly and, even with what we have lost, how much we have compared to many others. When my 11-year-old son asked, "Dad, will we still have enough money for me to go to college?" my answer was "Yes, we will find a way, and isn't it wonderful that we live in a country where you don't have to ask whether or not we will have food to eat tomorrow."

The lessons my family and I have learned in the last year were forced on us by unconscionable acts of terror and resultant feelings of fear, revulsion, grief, anger and hate. The lessons themselves, however, have become focused on appreciation, pride, gratitude, respect, perspective and understanding. The events of September 11th have changed all of our lives in so many ways. How we respond to those changes is the legacy we dedicate to our families, our world and ourselves. This anniversary of tragedy provides an opportunity to reflect on our feelings and emotions, re-evaluate our priorities, reaffirm our faith and remember the lessons that history has tried to teach us. Our prayer is that "United We Stand" will someday be the motto of the world.

The Cochran Family

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Clinical Research

A Practice-Based, Randomized, Controlled Clinical Trial of a New Resin Composite Restorative: One-Year Results

MA Wilson • AJ Cowan • RC Randall
RJ Crisp • NHF Wilson

Clinical Relevance

One-year data suggests that Z250 has potential as an alternative to amalgam in the restoration of selected posterior teeth.

SUMMARY

This study evaluated the performance of a low-shrinking resin composite compared with an amalgam for restoration of Class I and II cavities of moderate size in posterior teeth in a general practice setting. Fifty-two pairs of test and control restorations were placed in 49 patients. Clinical evaluations and assessments of replica models were carried out at baseline, six months and one year. Patients recorded their level of satisfaction with the restorations by means of visual analog scales. Apart from one control restoration that failed due to a fractured cusp, all of the restorations reviewed at six months and one year were intact with no unacceptable scores for any of the evaluation criteria. It was concluded that the resin composite evaluated, when used in conjunction with the recommended adhesive system, may be an appropriate alternative to amalgam in the restoration of posterior teeth over one year in clinical service.

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INTRODUCTION

The continuing development of resin composite restoratives has led to the availability of materials worthy of testing as alternatives to traditional restoratives used in the restoration of posterior teeth (Wilson, Dunne & Gainesford, 1997). The test material, Z250 (3M ESPE, St Paul, MN 55144, USA), is a resin composite that has been modified to exhibit lower polymerization shrinkage, higher fracture toughness and superior curing characteristics when compared to its predecessor, Z100 (3M ESPE). The resin system in Z250 has been modified by eliminating the BISGMA content and reducing the amount of TEGDMA; the new resin consists of UDMA and BIS-EMA(6) plus a small amount of TEGDMA. UDMA and BIS-EMA are higher molecular weight resins with fewer double bonds per unit of weight. The higher molecular weight results in lower shrinkage (personal communication Dr Brian Holmes, 3M ESPE). Singlebond (3M ESPE) is recommended to bond Z250 to tooth structure.

Clinical testing of restorative materials often takes the form of pragmatic studies with no control material for comparison. This type of study is appropriate for clinical research but the play of chance on the result may be great (Randall & Wilson, 1999). Many studies are carried out in university clinical settings where time and costs are usually lower than in general practice. This can challenge applying the results to individual patients who are treated in general practice. Generating clinical evidence for general dental practitioners (GDPs) by GDPs has an appealing logic. Studies to evaluate clinical outcomes compared to general dental practice are valuable in providing “real world” information on treatment effectiveness (Wilson & Mjör, 1997; Bader & Ismail, 1999). There are difficulties inherent in running GDP-based research (Hopkins & Eaton, 1996; Mackie, 1998), and good study design is paramount to ensuring that valid data is obtained (Wilson & Mjör, 1997). More research rooted in general practice is needed (Fallowfield, 1996; Wilson & Mjör, 1997; Bader & Ismail, 1999).

Aim

This study evaluated the performance of a low-shrinking composite as an alternative to dental amalgam in the restoration of moderate-sized Class I and II cavities in premolar and permanent molars of adult dental patients in a general dental practice setting.

Hypothesis

The test hypothesis was that the low-shrinking resin composite material would offer comparable performance to that of amalgam in the restoration of posterior teeth.

METHODS AND MATERIALS

The study was designed as a randomized controlled clinical trial to be carried out in a general dental practice setting in the UK to evaluate the performance of Z250 when used in conjunction with Singlebond dental adhesive (SB) in the restoration of moderate-sized Class I and Class II cavities in the permanent posterior teeth of adult patients. The control material was Dispersalloy (DeTrey Dentsply, Konstanz, Germany), a widely used dental amalgam. Ethics Committee approval was obtained prior to commencement of the clinical trial and written informed consent was obtained from each participant prior to being recruited into the study. The participants were free to withdraw from the trial, without reason, at any stage of the evaluation.

Patient Inclusion and Exclusion Criteria

Included in the study were patients with:

- A pair of similar lesions or failed restorations in vital premolar or permanent molars that required new or replacement Class I or two-surface Class II restorations of moderate size. For purposes of the study, a moderate-sized restoration was considered to extend between one quarter and no more than one third of the way up one or more cuspal slopes and/or had a proximal portion with at least one margin that obviously extended into the interproximal embrasure. A tooth was considered vital if it was clinically and/or radiographically free from any signs or symptoms of periapical pathology and responded to routine vitality testing.
- Molar-supported, anterior or canine-guided dentitions free from any edentulous spaces and occlusal interferences of clinical significance.
- Patients ranged in age between 18 and 75 years of age, gave informed written consent and were available for recall appointments.

Patients were excluded from the study if:

- Any teeth opposing or adjacent to the teeth included in the study required replacement or repair of any restorations.
- They were participating in the clinical evaluation of other restorative materials or systems involving posterior teeth.
- There was a history of adverse reaction to clinical materials of the types used in the evaluation or a medical or dental history that could complicate the provision of the proposed restorations.

Besides the inclusion and exclusion criteria listed above, the teeth selected for the study shared sound proximal contacts with adjacent teeth, where appropriate, and were free of cracks and other defects that would necessitate operative intervention other than the restoration undertaken as part of the study. Teeth were excluded if they had the remaining dentin thickness of <0.5mm following completion of the preparation.

The tooth/teeth to be restored were prepared using conventional instruments and techniques under rubber dam. No bevels were placed on the cavity cavosurface angles occusally, proximally or gingivally. Restorations were randomly allocated to teeth by using a computer generated random numbers scheme. The randomization process was stratified to ensure that each patient received a test and control restoration, and up to two pairs of restorations were placed per patient. One investigator (AJC) placed the restorations according to manufacturer's instructions and carried out the baseline evaluations. Restoration placements followed manufacturer's directions for use.

Baseline data for each restoration were obtained between one week and one month of placement follow-

Table 1: *Codes and Criteria for the Assessment of the Restorations*

Criteria	Code	Definition
Color match	A	Restoration matches adjacent tooth structure in color and translucency.
	B	Mismatch is within an acceptable range of tooth color and translucency.
	C	Mismatch is outside the acceptable range.
Marginal adaptation	A	Restoration closely adapted to the tooth. No explorer catch at the margins, or if there was a catch, it was only in one direction. No crevice visible.
	B	Explorer catch. No visible evidence of a crevice into which the explorer can penetrate. No dentin or base visible.
	C	Explorer penetrates into a crevice that is of a depth that exposes dentin or base.
Anatomic form	A	Restoration continuous with existing anatomic form.
	B	Restoration discontinuous with existing anatomic form but missing material not sufficient to expose dentin or base.
	C	Sufficient material lost to expose dentin or base.
Surface roughness	A	Surface of restoration is smooth.
	B	Surface of restoration is slightly rough or pitted, but can be refinished.
	C	Surface deeply pitted, irregular grooves (not related to anatomy) and cannot be refinished.
	D	Surface is fractured or flaking.
Marginal staining	A	No staining along cavosurface margin.
	B	<10% of cavosurface margin affected by stain.
	C	>10% <25% of cavosurface margin affected by stain.
	D	>25% <50% of cavosurface margin affected by stain
	E	>50% of cavosurface margin affected by stain.
Interfacial staining	A	No staining of the tooth/restoration interface.
	B	<10% of the tooth/restoration interface with interfacial staining.
	C	>10% <25% of the tooth/restoration interface with interfacial staining.
	D	>25% <50% of the tooth/restoration interface with interfacial staining.
	E	>50% of the tooth/restoration interface with interfacial staining.
Occlusal contacts	H	Heavy.
	N	Normal.
	L	Light.
	A	Absent.
Proximal contacts	H	Heavy.
	N	Normal.
	L	Light.
	O	Open.
Sensitivity	1	None.
	2	Mild but bearable.
	3	Uncomfortable.
	4	Painful.
Secondary caries	A	No secondary caries present.
	B	Secondary caries present.

ing any necessary modifications, such as occlusal adjustments and refinement of the marginal adaptation and surface finish. The amalgam restorations were polished at this appointment. Patients who failed to attend three baseline review appointments within the timeframe of one week and one month were excluded from the study and replaced. At the six-month and one-year recalls the restorations were initially examined to determine clinical acceptability and were then assessed using the codes and criteria set out in Table 1. Two calibrated investigators undertook the recall evaluations, seeing each patient independently; where examiners differed in their assessments, consensus was reached through discussion. The investigators assigned to review the restorations had a reproducibility rate of restoration assessments of at least 85%.

After cavity preparation at baseline and each recall appointment, a dual arch polyvinyl siloxane impression was taken of each tooth included in the study together with its opponent and the opposing abuting tooth/teeth. In addition, a photographic record was made of each restoration, including a 1.5x occlusal view. The diestone replica models obtained were assessed for marginal adaptation, anatomic form, surface finish and wear, and for wear of cusps opposing the test restorations. These assessments were carried out blind by one investigator (RJC).

The patients were asked at the baseline review appointment to score their level of comfort and satisfaction with the appearance of the test restorations, their confidence in chewing on the restorations and which material they preferred. The responses were recorded on visual analogue scales of 1 to 10.

Statistical Analysis

The results were analyzed by means of the McNemar chi-square test and Wilcoxon test, as appropriate.

Table 2: *Distribution of Teeth Included in the Study According to Tooth Type and Class of Restoration*

	Z250		**Dispersalloy**	
	Class I	Class II	Class I	Class II
Maxillary				
Molars	6	7	8	9
Premolars	1	14	1	13
Mandibular				
Molars	10	10	8	7
Premolars	0	5	0	7
Total	17	36	17	36

Table 3: *Summary of the Clinical Assessments of Test and (Control) Materials at Baseline, Six Months and One Year. % Alpha Scores*

Criteria	**Baseline**	**6 Months**	**One Year**
Clinical Acceptability	100 (100) [1.00]*	100 (100) [1.00]	100 (98) [1.00]
Color Match	90 (-) [-]	93 (-)	92 (-)
Marginal Adaptation			
1. Occlusal	100 (100) [1.00]	88 (98) [0.046]	90 (92) [0.66]
2. Proximal	100 (100) [1.00]	96 (100) [0.32]	100 (96) [0.32]
Anatomic Form			
1.Occlusal	100 (100) [1.00]	100 (100) [1.00]	98 (98) [1.00]
2.Proximal	100 (97) [0.32]	100 (96) [0.32]	100 (100) [0.32]
Surface Roughness			
1. Occlusal	96 (98) [0.32]	95 (91) [0.32]	98 (92) [0.83]
2. Proximal	100 (100) [1.00]	100 (100) [1.00]	97 (100) [1.00]
Marginal Staining			
1.Occlusal	100 (100) [1.00]	100 (100) [1.00]	96 (100) [0.16]
2.Proximal	100 (97) [0.32]	100 (100) [1.00]	100 (100) [1.00]
Interfacial Staining			
1.Occlusal	100 (98) [0.32]	100 (100) [1.00]	98 (100) [0.32]
2.Proximal	100 (100) [1.00]	100 (100) [1.00]	100 (100) [1.00]
Sensitivity	96 (96) [1.00]	98 (98) [1.00]	98 (96) [0.56]
Secondary Caries	100 (100) [1.00]	100 (100) [1.00]	100 (100) [1.00]
Gingival Health	96 (96) [1.00]	95 (95) [1.00]	94 (96) [0.32]

**p-values from McNemar chi-square test or Wilcoxon sign rank test as appropriate, comparing the two groups.*

RESULTS

Fifty patients were recruited to participate in the study with an overall male: female ratio of *circa* 1:1. All placements and baseline assessments were completed within four months of the commencement of the study. Table 2 shows distribution of the teeth included in the study according to tooth type and Class of restoration. Fifty-three pairs of restorations were placed in the 50 patients who participated; 60% in molars and 75% in Class II. Of these, 52 pairs (98%) of restorations placed in 49 patients were reviewed at baseline, with the mean patient age being 35 years. At one-year, 49 pairs of restorations were reviewed and there was a 96% recall rate relative to the baseline review; 34 pairs (65%) were Class II and 15 pairs (29%) were Class I. Table 3 shows the results of the clinical assessments and recall rates are provided in Table 4.

Results of the replica model assessment are given in Table 5. Evaluation of casts of the cavities prior to insertion of the test and control materials confirmed that the paired restorations in each patient were of comparable size. All the restorations were found to be clinically acceptable at six months. At one year all the Z250 restorations were clinically acceptable but one of the control (Dispersalloy) Class II restorations had failed as a consequence of a fractured cusp. Assessment of the casts of the test and control restorations at six months and one year revealed no apparent wear on opposing cusp wear.

Statistical analysis of the data failed to reveal any statistically significant differences except in relation to appearance.

Mean scores for the patient VAS ratings were:

1. Rate the comfort of the restorations where 0 = very comfortable and 10 = uncomfortable.

Composite	1.2	(range 0 to 4.9)
Amalgam	1.4	(range 0 to 5.1)

2. Rate the appearance of the restorations where 0 = very pleased and 10 = dissatisfied.

Composite	0.9	(range 0 to 4.6)
Amalgam	2.5	(range 0 to 9.7)

3. Rate confidence for chewing on the restoration, where 0 = confident and 10 = hesitant.

Composite	1.1	(range 0 to 9.5)
Amalgam	1.1	(range 0 to 9.3)

4. When asked which material they preferred, 96% of the patients chose the composite material.

Table 4: *Number of Pairs of Restorations Reviewed and Recall Rate %*

	Baseline	Six Months	One Year
Class I	17	16	15
Class II	35	26	34
Recall rate	100%	82%	96%

Table 5: *Summary of Replica Model Assessments at Baseline, Six Months and One Year. % Alpha Scores.*

	Baseline		Six Months		One Year	
	Z250	Dispersalloy	Z250	Dispersalloy	Z250	Dispersalloy
Anatomic form	100	100	100	100	98	100
Marginal adaptation	100	100	90	100	88	95
Surface roughness	100	100	100	95	100	95

DISCUSSION

This randomized, controlled study evaluated the performance of Z250 in the environment of a general dental practice. Significant effort in technological development of resin composite chemistry is directed towards the production of lower shrinking materials (Eick & others, 1993). Polymerization contraction stress can reduce the effectiveness of the adhesive bond-to-tooth structure, leading to an increased risk of post-operative sensitivity, secondary caries and marginal breakdown of the resin composite (Jörgensen, Asmussen & Shimokobe, 1975; Davidson, de Gee & Feilzer, 1984; Eick & others, 1993; Uno & Shimokobe, 1994; Kinomoto & Torii, 1998; Griffiths & others, 1999; Condon & Ferracane, 2000; Dauvillier & others, 2000). Many techniques have been developed to reduce these effects of polymerization shrinkage, including incremental placement (Jensen & Chan, 1985; Craig, 1997), sealing the cavity margins with a glaze of unfilled resin (Kemp-Scholte & Davidson, 1988; Tjan & Tan, 1991), beveling enamel margins (Han, Okamoto & Iwaku, 1990), use of staged light curing (Mehl, Hickel & Kunzelmann, 1997; Sakaguchi & Berge, 1998; Yoshikawa, Burrow & Tagami, 2001) or use of a glass ionomer as a base or liner (Kemp-Scholte & Davidson, 1990).

Modification of Z250 to produce a material with reduced polymerization shrinkage merits clinical testing to establish its treatment efficiency. The general practice setting selected for this study, with the usual background constraints of routine patient treatment, was considered to strengthen the relevance of the findings in regards to the real world of everyday clinical practice.

The six-month and one year findings revealed a similar incidence of limited deterioration in occlusal marginal adaptation for the test and control materials (Table 2). Some occlusal marginal staining was observed in two restorations of Z250 that had also been assessed as Bravo for occlusal marginal adaptation. Of these, one restoration scored Bravo for color match, occlusal and proximal anatomic form, surface roughness and interfacial occlusal staining. The scores for anatomic form for both groups of restorations were similar although the amalgam restorations showed a higher number of Bravo scores (8%) for surface roughness compared with the resin composite restorations (2%). Overall, however, the performance of the Z250 restorations at one year demonstrated no clinically detectable deterioration; retrospective assessment of the casts confirmed these clinical findings. The study participants were asked to indicate their level of satisfaction with the study restorations by means of VAS scales. Functionally, there was no difference between the materials but from the esthetic viewpoint, a clear preference was demonstrated for the resin composite restoration compared with the amalgam.

One-year clinical data, as reported here, is short-term. The justification for publishing such early results can be had from the lack of clinical data accompanying the launch of new resin composite materials. FDA and European CE marking requirements are such that no clinical data is required for registration or launch of these products. One-year clinical data, however, is of restricted value and further long-term follow-up is desirable, as is intended in this product evaluation.

The setting for this study was a well-established, mixed National Health Service (NHS)/private dental practice in a town in the north of England. The sample of 50 participants and the inclusion/exclusion criteria applied to their recruitment into the trial narrows the interpretive value of the data obtained. No one study can be expected to provide a definitive answer to a clinical question as the biological diversity of mankind is too great (Gleick, 1987; Jenicek, 1989). By incorporating a randomization scheme into the design of the study, the effect of bias or chance on the results was reduced. A 50-patient sample size can be considered small, although it may be sufficient given the anticipated deterioration in amalgam restorations in terms of marginal adaptation and the critical importance of this in the practitioner decision-making process to replace these restorations. Further vindication for the sample size is that, should other studies of similar design and objectives be published, the potential would exist for further evaluation of the data by means of meta-analysis. In the meantime, arrangements are underway to complete a two-year review that will include comparative SEM examination of selected epoxy resin replicas of the restorations.

CONCLUSIONS

Results from this practice-based, randomized, controlled clinical trial indicated that Z250, when used in conjunction with Singlebond adhesive system, gave a clinically acceptable performance in Class I and II restorations of moderate size and could be considered to be an appropriate alternative to amalgam in the restoration of posterior teeth over one-year in clinical service.

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A Clinical Comparison of Glass Ionomer, Resin-Modified Glass Ionomer and Resin Composite Restorations in the Treatment of Cervical Caries in Xerostomic Head and Neck Radiation Patients

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Clinical Relevance

Glass ionomer restorative materials provide clinical caries inhibition but are susceptible to fluoride gel erosion in xerostomic patients, whereas resin composite provides greater structural integrity.

SUMMARY

Controversy exists as to whether there is less secondary caries at the margins of glass ionomer restorations compared with other materials that do not release fluoride. This study examined the incidence of secondary caries for three types of restorative materials in Class V restorations in xerostomic patients. The study group consisted of 45 high caries-risk adult patients who had undergone head and neck irradiation for the treatment of cancer. All were substantially xerostomic and in need of at least three restorations in the same arch. Every patient received a restoration with each of the test materials, a conventional glass ionomer (GI), a resin modified glass ionomer (RMGI) and a resin composite (C). Patients were instructed in the daily use of a neutral pH sodium fluoride gel in custom trays. Recall appointments were made at 6, 12, 18 and 24 months, and the restorations were examined for material loss, marginal integrity and recurrent caries at the restoration margin. Fluoride compliance was determined at each recall period and recorded as the percentage of recommended use during that interval. Patients were categorized at the end of the study as fluoride non-users if their average compliance was 50% or less. Those with greater than 50% compliance were categorized as fluoride users. In the latter group, no recurrent caries was found for any of the restorations, whereas a material-dependent incidence of recurrent caries was found in the fluoride non-user group. None of the GI, one RMGI and eight C restorations failed due to recurrent caries. For the fluoride non-user patients, Fishers exact test (p=0.05) showed no statistical difference between GI and RMGI but statistical differences were found among those materials and resin composite at each recall period.

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Recurrent caries reductions for GI and RMGI relative to C were greater than 80% in xerostomic patients not using topical fluoride supplementation.

INTRODUCTION

Studies of placement and replacement of restorations over the last two decades in various populations continue to document the overwhelming evidence from clinical practice that recurrent decay is the single most frequent factor involved in their failure (MacInnis, Ismail & Brogan, 1991; Mjör, 1986, 1997; Qvist, Thylstrup & Mjör 1986a, 1986b; Wilson, Burke & Mjör, 1997). Replacement restorations now represent a greater proportion of the workload for dentists than the operative treatment of primary caries. The potential benefit to patients from restorative materials that provide caries inhibition is clear.

Since the early clinical observations that silicate restorations demonstrated caries inhibition, there has been interest in fluoridated restorative materials for prevention of recurrent caries. Conventional glass ionomer cements provide a tooth colored, fluoride releasing material (Thornton, Retief & Bradley, 1986) that bonds chemically to enamel and dentin (Powis & others, 1982) and which provides fluoride uptake by dental tissues (Retief & others, 1984). Glass ionomer materials have been shown to release similar levels of fluoride to silicates *in vitro* (Swartz, Phillips & Clarke, 1984; Christensen & others, 1998). Fluoride release is initially high but decreases to a long-term low level in about three weeks *in vitro* (Perrin, Persin & Sarrazin, 1994) to an amount equivalent to 0.5 ppm at one year. Fluoride release increases in an acidic milieu, probably due to surface erosion (Forsten, 1998). An extensive review of the *in vitro* literature provides support for the ability of high fluoride releasing materials to prevent demineralization of adjacent tooth structure (Burgess, 1998). However, there is only a modest amount of supportive clinical evidence. Information from a small number of controlled clinical studies and individual practices has provided positive evidence of caries inhibition (Swift, 1986; Wilson & McLean, 1988; Tyas, 1991; Wood, Maxymiw & McComb, 1998), but large general practice surveys have been unable to document any significant effect on rates of recurrent caries (Mjör, 1997; Wilson & others, 1993). Validation of *in vivo* caries inhibition by available fluoridated restorative materials, therefore, requires additional prospective, randomized clinical trials.

In recent years, a new class of glass ionomer materials has been developed (Mitra, 1991a) that is a hybridization of glass ionomer and resin composite technology. Such materials provide photopolymerization capabilities, improved handling characteristics and better aesthetics. Fluoride release (Mitra, 1991b) as well as *in vitro* caries inhibition (Griffin, Donly & Erickson, 1992; Souto & Donly, 1993; Nagamine & others, 1997) are similar to conventional glass ionomers. Controlled clinical studies are also lacking for these novel photopolymerized glass ionomer materials. In a clinical study that utilized conventional glass ionomer cements for treatment of radiation caries, the restorations were degraded within six months in patients using a mildly acidic home-use fluoride gel (Wood & others, 1993). In a small number of fluoride non-compliant patients, the glass ionomer restorations performed better than the amalgam restorations, as no recurrent decay was associated with their margins. Materials are therefore required that will provide caries inhibition in addition to adequate longevity under different oral conditions. The resin-modified glass ionomer materials have the theoretical potential to provide similar preventive action as conventional glass ionomers combined with improved resistance to degradation. This hypothesis needs to be tested *in vivo*.

Post-radiation xerostomic patients provide an ideal population to investigate material effects. Therapeutic ionizing radiation has a deleterious effect on the human dentition (Brown & others, 1978; Anneroth, Holm & Karlsson, 1985). High caries rates are present and restoration longevity is generally reduced due to the increased susceptibility to recurrent caries. Xerostomia, coupled with qualitative changes in the saliva and increased carbohydrate intake by the oncology patient, results in a hostile environment for both natural teeth and restorative materials. Radiation caries typically present as softening or cavitation at the neck of the tooth, the Class V carious lesion. Historically, patients were rendered edentulous prior to radiation therapy to eliminate post-radiation caries problems. Currently, maintenance of the dentition is recommended wherever feasible, using robust permanent restorations, improved patient education and daily application of a fluoride gel (Myers & Mitchell, 1988).

Xerostomic patients present a unique population for the study of preventive restorative materials due to their increased susceptibility to recurrent caries.

The three most popular direct restorative materials currently used for radiation caries are silver amalgam, resin composite and glass ionomer (polyalkenoate). Silver amalgam was not considered in this study because it lacked the aesthetic properties desired in these patients and was the subject of a prior study (Wood & others, 1993). The purpose of this clinical study was two-fold: a) to test for *in vivo* evidence of caries inhibition at the margins of glass ionomer restorations compared with a non-fluoridated resin composite and b) to determine the optimal aesthetic restorative material for restorative treatment in the high caries-risk, post-radiation patient.

METHODS AND MATERIALS

To be included in the study, a patient needed at least three cervical carious lesions in the same arch. Caries was defined as either frank, visible cavitation or significant softening of tooth structure by careful manual probing following dental prophylaxis. All patients had received prior radiation therapy involving the head and neck, were 18 years of age or older and were capable of giving informed consent. Patients were advised that all materials were in general clinical use and no experimental or new material was being utilized. Ethical approval was obtained from the clinical trials committee and the ethics committee at the authors' institutions. Patients who could not attend for at least one recall appointment were excluded. Patients were expected to come for four appointments over a two-year period, but in light of the population studied (cancer patients), it was anticipated that not all patients would be capable of completing the two-year cycle.

Three restorative materials: an encapsulated conventional glass ionomer cement (GI) (Ketac-Fil, 3M ESPE Dental Products, St Paul, MN 55144, USA) a command set resin-modified glass ionomer-resin (RMGI) (Vitremer, 3M ESPE) and a photopolymerized resin composite restorative material (C) (Z-100, 3M ESPE) were used in this study. Each patient received all three materials in the same quadrant or sextent of their mouth. The three teeth included as each study set received one restoration of each material. Placement was based on an allocation table developed prior to commencement of the study, such that each material was placed in the more anterior, middle or posterior tooth position an equal number of times. Materials were utilized according to manufacturer's instructions except no preconditioning with polyacrylic acid was used for either form of glass ionomer material.

Box-form cavity preparation with parallel walls, a distinct pulpal floor and no retention grooves was used for all restorations. A combination of high-speed and slow-speed instrumentation was used as clinically necessary. The occlusal enamel wall was lightly beveled for resin composite only. A calcium hydroxide cement was used only if the preparation was in proximity to the pulp. The encapsulated conventional glass ionomer cement insertion involved using a clear plastic matrix form (Premier Cure-Thru Cervical Matrices, Premier Dental Products Co, Plymouth Meeting, PA 19462, USA) and the restoration was allowed to set for five minutes after which a thick coat of enamel bonding resin was applied. Excess material was removed using a sharp blade, scaler or gold-knife. A new coating of resin was then applied and photopolymerized. Restoration refinement was carried out at a later visit, within one to two weeks, using high-speed, multi-fluted carbide burs for gross excess followed by abrasive discs (Sof-Lex Discs, 3M ESPE). The resin-modified

Table 1: *Evaluation Criteria for Assessment of Marginal Adaptation*

Grade 1. The restoration appears to adapt closely to the tooth along its periphery, with no crevice formation. An explorer will not catch on being drawn across the margin, or if it does catch, then it will only be in one direction.
Grade 2. A sharp explorer will catch in both directions and there is visible evidence of early crevice formation into which the explorer will penetrate. Dentin and lining are not visible.
Grade 3. A blunted explorer will penetrate and will catch in both directions, and there is visible evidence of early crevice formation into which the explorer will penetrate. Dentin and lining are not visible.
Grade 4. An explorer will penetrate into the crevice to a sufficient depth that the dentin or lining is exposed. **The restoration has failed and will require replacement.**
Grade 5. The restoration is fractured or lost. **The restoration has failed and will require replacement.**

Table 2: *Criteria for the Assessment of Anatomical Form*

Grade 1. The restoration is continuous with the existing anatomy of the tooth.
Grade 2. The restoration is not in continuity with the existing anatomy of the tooth but the discontinuity is insufficient to expose dentin or lining material and, hence, the restoration is clinically acceptable.
Grade 3. The restoration is not in continuity with the existing anatomy of the tooth; the discontinuity is sufficient to expose dentin or lining. **The restoration has failed and will require replacement.**

Table 3: *Evaluation Criteria for Recurrent Caries*

Grade 1. Softness of the surface texture or a surface defect adjacent to the restoration is not greater than 0.5 mm in greatest diameter.
Grade 2. Softening of the surface texture is such that the surface can be penetrated or a surface defect is greater than 0.5 mm and less than 3 mm in greatest diameter**. The restoration has failed and requires replacement.**
Grade 3. Frank peripheral decay involves a section of tooth/filling margin greater than 3 mm in length. **The restoration has failed and will require replacement.**

glass ionomer insertion involved the use of the manufacturer's primer resin for 30 seconds on the internal walls followed by drying and photopolymerization. A glossy appearance was ensured. After careful dispensing of powder and liquid, the RMGI components were mixed and placed in a centric syringe for ease of insertion. The restoration was contoured to the approximate shape using a flat plastic instrument and optimally photocured with a conventional halogen unit for 40 seconds prior to immediate finishing in the manner described for final finishing of conventional glass ionomer. Finishing gloss was applied and photocured after restoration refinement. Resin composite restorations involved use of an enamel/dentin bonding system (Scotchbond Multi-Purpose, 3M ESPE Dental Products). Enamel was conditioned using phosphoric acid for 30 seconds, and dentin for 15 seconds followed by thorough washing and light drying prior to two coats of primer. After air drying the primer, a thin adhesive resin layer was evenly applied and photopolymerized. Resin composite was inserted, contoured using hand instruments and photopolymerized. If the cavity was extensive in a gingivo-occlusal direction (>2.5mm), the composite was placed in two lateral incremental layers. Immediate finishing was carried out using the same protocol as for the other two materials. Patients were prescribed a daily neutral sodium fluoride gel tray application (Neutrogel, Germiphene Company Ltd, Brantford, Ontario, Canada N3T 5V7) to prevent new caries. This is clinic policy for this patient population and was not abrogated for the purposes of this study. Patients used a visual analog scale (VAS), ranging from 0-100% at each recall, to portray their fluoride compliance (Wood & others, 1993). From this, and in discussion with the patient, a percentage estimation of fluoride use in the previous six months was ascertained. If a patient documented fluoride use of 50% or less over the previous six months, they were classified as a "non-fluoride user," whereas if they documented fluoride use more than 50% of the time, they were classified as a fluoride user.

Restoration evaluation was carried out by one clinician (REW) using specific criteria at each six-month recall appointment. Of the 50 sets of restorations placed, six were excluded prior to any recall period due to death (four patients) or withdrawal (two patients). Assessment of marginal adaptation (Table 1), anatomical form (Table 2) and recurrent (marginal) caries (Table 3) were specifically recorded. Clinical assessment documented changes in physical aspects of the restorations and adjacent tooth structure. The diagnosis of recurrent caries involved the presence of irregular, softened or cavitated tooth structure immediately adjacent to the restoration boundary as determined by tactile exploration. The examining clinician was not blinded to the nature of the restorations since they appear different clinically from one another. Photographs of the restoration following completion and at six-month intervals were exposed when possible. Assessment of restoration failure was based on pre-established criteria.

Prior to the completion of the study, it was apparent that significant erosion of the conventional glass ionomer was occurring. Based on this finding, a recommendation was made to cease using conventional glass ionomer in this type of patient. This occurred after 44 sets of restorations had been placed. Therefore, the final six patients received only two restoration types. The cumulative failure rates of the cervical restorations were compared among the groups of three restorative materials at 6, 12, 18 and 24 months using the Pearson Chi-square and the Fisher Exact test. Stratified analyses were also conducted for subjects who used, on average, more than 50% fluoride (fluoride-users) during the two-year study period and those who used 50% or less fluoride (fluoride non-users). Statistical tests were two-tailed and interpreted at the 5% significance level.

RESULTS

Analysis of all restoration failures, in all patients, revealed a significantly greater number of restoration failures for the conventional glass ionomer than for the resin-modified glass ionomer and resin composite restorations. The latter two materials showed essentially equal rates of restoration failure, with no statistically significant differences between them (Table 4). It should be noted that for all tables the numerator is the cumulative number of failures and the denominator is the sum of the number of restorations evaluated at each recall plus the cumulative number of failures recorded at prior recalls.

The considerable number of conventional GI restoration failures was attributed to loss of anatomic form/marginal adaptation (Table 5). It was for this reason that the final group of six patients did not receive conventional glass ionomer restorations. Analysis according to fluoride usage revealed that these GI failures were due to erosion effects related to fluoride use and/or possible combination of physical effects of xerostomia and fluoride erosion (Tables 6a & 6b). No differences were found among materials with regard to marginal adaptation/anatomic form for patients with low average fluoride use (Table 6a), whereas fluoride users showed erosion of conventional glass ionomer despite the use of a neutral pH gel (Table 6b). By 24 months, the anatomic form/marginal adaptation difference between GI and RMGI was less clear, with no significant differences between the two materials (Table 5). Prior to 18 months, there was no statistically significant difference in erosion between RMGI and C, but from 18 months, the resin composite revealed longer-term stability in the presence of fluoride. No resin composite restorations failed due to problems of marginal adaptation or anatomical form in fluoride-compliant patients (Table 6b). The behavior of the resin-modified glass ionomer was intermediate with respect to erosion effects.

No conventional glass ionomer restoration failures due to marginal caries were documented throughout the study, and only one resin-modified glass ionomer restoration required replacement due to recurrent caries. However, due to the small size of the study, statistically significant material differences in relation to caries inhibition could not be demonstrated when all patients, independent of fluoride compliance, were included (Table 7). Borderline significance was shown between GI and C at six months and between RMGI and C at 12 and 18 months. By 24 months, the small number of evaluated or surviving restorations was insufficient to provide significance despite the fact that 44% of the resin composite restorations, eight out of 18, had failed due to recurrent decay.

No restoration failures due to marginal caries were documented in patients designated fluoride compliant and those who used their fluoride more than 50% of the time for the study duration (Table 8b). Statistically significant differences in caries inhibition were revealed in the fluoride non-compliant patients (Table 8a). At three time periods, GI was significantly more effective than C in reducing the incidence of recurrent marginal decay. By 24 months, the low numbers of evaluated restorations did not allow statistical significance despite the fact that no GI restorations failed due to marginal caries compared with 67% (8/12) of C restorations. Similarly, statistically significant differences were shown at all time periods except for six months between C and RMGI, revealing material effect differences on caries inhibition.

Table 4: *All Class V Restoration Failures, Independent of Cause and Patient Fluoride Use*

	Recall Time Cumulative Failures/ Recall Evaluations (%)			
Restorative Material	**6 Months**	**12 Months**	**18 Months**	**24 Months**
GI	16/38[a] (42%)	23/35[a] (66%)	24/30[a] (80%)	25/28[a] (89%)
RMGI	5/44[b] (11%)	8/38[b] (21%)	13/26[b] (50%)	14/21[ab] (67%)
C	6/44[b] (14%)	9/37[b] (24%)	10/26[b] (38%)	10/20[b] (50%)

For each time period: groups with the same letter are not significantly different at $p<0.05$.

Table 5: *Class V Restoration Failures Due To Marginal Adaptation and/or Anatomical Form Independent of Fluoride Use*

	Recall Time Cumulative Failures/ Recall Evaluations (%)			
Restorative Material	**6 Months**	**12 Months**	**18 Months**	**24 Months**
GI	16/38[a] (42%)	23/35[a] (66%)	24/30[a] (80%)	25/28[a] (89%)
RMGI	5/44[b] (11%)	8/38[b] (21%)	13/26[b] (50%)	14/21[ab] (67%)
C	4/44[b] (9%)	6/35[b] (17%)	7/23[b] (30%)	7/17[b] (41%)

For each time period: groups with the same letter are not significantly different at $p<0.05$.

Table 6a: *Class V Restoration Failures Due To Marginal Adaptation and/or Anatomical Form in Fluoride Non-users (≤ 50% Average Use)*

	Recall Time Cumulative Failures/ Recall Evaluations (%)			
Restorative Material	**6 Months**	**12 Months**	**18 Months**	**24 Months**
GI	4/22[a] (18%)	7/19[a] (37%)	8/14[a] (57%)	9/12[a] (75%)
RMGI	3/24[a] (12.5%)	5/20[a] (25%)	6/15[a] (40%)	7/13[a] (54%)
C	4/24[a] (17%)	6/17[a] (35%)	7/12[a] (58%)	7/11[a] (64%)

For each time period: groups with the same letter are not significantly different at $p<0.05$.

Table 6b: *Class V Restoration Failures Due To Marginal Adaptation and/or Anatomical Form in Fluoride Users (>50% Average Use)*

	Recall Time Cumulative Failures/ Recall Evaluations (%)			
Restorative Material	**6 Months**	**12 Months**	**18 Months**	**24 Months**
GI	12/16[a] (75%)	16/16[a] (100%)	—	—
RMGI	2/20[b] (10%)	3/18[b] (17%)	7/11[b] (64%)	7/8[a] (88%)
C	0/20[b]	0/18[b]	0/11[c]	0/6[b]

For each time period: groups with the same letter are not significantly different at $p<0.05$.

DISCUSSION

The post-radiation xerostomic patient presents an extremely challenging oral milieu. High caries rates are present and restoration longevity is generally greatly reduced. Restoration deterioration and failure events tend to occur more rapidly in post-radiation patients than in normal, healthy individuals. Such patients, therefore, provide an ideal population to investigate material effects in a reduced timeframe. The specific patient population investigated in this study was particularly challenging, as it included a high proportion of alcohol users, smokers and patients with less than ideal oral hygiene.

Table 7: *Class V Restoration Failures Due To Marginal Caries Independent of Fluoride Use*

	Recall Time Cumulative Failures/ Recall Evaluations (%)			
Restorative Material	**6 Months**	**12 Months**	**18 Months**	**24 Months**
GI	0/38[a]	0/19[a]	0/7[a]	0/4[a]
RMGI	1/44[a] (2%)	1/34[a] (3%)	1/19[a] (5%)	1/9[a] (11%)
C	5/44[a] (11%)	7/36[a] (19%)	8/24[a] (33%)	8/18[a] (44%)

For each time period: groups with the same letter are not significantly different at $p<0.05$.

Table 8a: *Class V Restoration Failures Due To Marginal Caries in Fluoride Non-users (≤ 50% Average Use)*

	Recall Time Cumulative Failures/ Recall Evaluations (%)			
Restorative Material	**6 Months**	**12 Months**	**18 Months**	**24 Months**
GI	0/22[b]	0/15[b]	0/7[b]	0/4[ab]
RMGI	1/24[ab] (4%)	1/18[b] (6%)	1/11[b] (9%)	1/8[b] (12.5%)
C	5/24[a] (21%)	7/18[a] (39%)	8/13[a] (62%)	8/12[a] (67%)

For each time period: groups with the same letter are not significantly different at $p<0.05$.

Table 8b: *Class V Restoration Failures Due To Marginal Caries in Fluoride Users (>50% Average Use)*

	Recall Time Cumulative Failures/ Recall Evaluations (%)			
Restorative Material	**6 Months**	**12 Months**	**18 Months**	**24 Months**
GI	0/16	0/4	—	—
RMGI	0/20	0/16	0/8	0/1
C	0/20	0/18	0/11	0/6

Differences in material behavior were shown in this small clinical study with regard to restoration longevity, durability and caries inhibition. These effects were largely dependent on the fluoride compliance of the study patients. Patients were assigned as fluoride-users or non-users based on their average fluoride use over the 24 months of the study. This was considered appropriate due to the fact that patients frequently recorded fluctuating levels of fluoride on the visual analog scale at different recalls. Topical fluoride gels have been used extensively as a means of preventing radiation caries *in vivo* (Jansma & others, 1989; Myers & Mitchell, 1988). A prior study (Wood & others, 1993) showed significant damage to conventional glass ionomer cements *in vivo*, using a mildly acidic (pH 5.6) sodium fluoride gel. Subsequent *in vitro* testing (el-Badrawy, McComb & Wood, 1993) of various fluoride gels with glass ionomer materials resulted in replacement of this mildly acidic daily topical fluoride gel with a neutral pH gel. Despite this, the conventional glass ionomer still showed poor durability in the xerostomic patients who were fluoride users. For those patients designated as fluoride non-users, it was documented that the GI showed no generalized erosion and caries inhibition at the restoration margins. The fairly rapid dissolution of the conventional glass-ionomer restorations with the use of neutral fluoride was unexpected. It would appear that the combination of xerostomia and fluoride use is particularly detrimental to glass ionomer materials. While the reasons are not known, it can be speculated that the lack of salivary buffering in the xerostomic patient may be conducive to developing a lower than normal plaque pH. This could result in a combination of H+ and Fl- to form hydrofluoric acid, which could erode the GI silicate-glass-hydrogel network. The severe erosion noted in the conventional GI restorations resulted in their non-placement in six of the study patients. Of these patients, two did not return for recalls and four were documented fluoride users. For these reasons and because the statistical analysis was performed using proportions of failures for each material separately, this deviation from the original protocol is considered to have had negligible impact on the study results.

The resin-composite material demonstrated excellent durability and resistance to erosion in fluoride-compliant xerostomic patients but less caries-inhibition than the other materials in the non fluoride-compliant patient. The resin-modified glass ionomer demonstrated improved durability over the conventional glass ionomer material and provided significant caries-inhibition in the non-fluoride user. Erosion from fluoride gel use did become apparent with the resin-modified glass ionomers later in the study. This is consistent with *in vitro* comparative studies (el-Badrawy & McComb, 1998). The patients who did not perform the home fluoride treatments showed more typical glass ionomer cement durability. Fluoridated materials therefore can provide localized caries control where fluoride is deficient. The concept of using preventive restorative materials containing fluoride is therefore most advantageous where low compliance with preventive advice is anticipated.

Recent epidemiological surveys from general practice have been unable to document evidence of reduced caries associated with using fluoridated glass ionomer materials in the general population. This is despite a significant amount of *in vitro*, *in situ* and *in vivo* research documenting fluoride release, fluoride tooth uptake and artificial caries inhibition from these materials (Burgess, 1998; McComb, 1998). The divergence of epidemiological results from the results of this study is an example of a difference between "efficacy" results from small carefully controlled studies and "effectiveness" results from a general practice population. This is frequently due to the significant patient, operator and material variables. Effectiveness of a therapeutic result can often be less apparent in large, general and varied populations where the number of variable factors masks specific therapeutic effect. These variables include skewed glass ionomer use in the high caries-risk patients, operator differences, patient factors and possible material or failure misclassification. The diagnosis of recurrent caries is not consistent among practitioners and may include stained or deteriorating margins. Restoration replacement is often advocated on the basis of conditions thought to be conducive to the development of recurrent caries as opposed to the actual presence of disease. Such differing definitions of recurrent caries may, therefore, mask the actual therapeutic effect of fluoridated restorative materials.

The results of this study provide supportive clinical evidence for local therapeutic caries inhibition by fluoridated glass-ionomer restorative materials, both conventional and resin-modified, in the fluoride non-compliant patient. The fact that retrospective general practice studies do not as yet provide supportive evidence can be due to the factors cited but could also mean that this effect may be limited and can be overwhelmed. Controlled clinical trials of longer duration would be instructive in resolving this issue.

CONCLUSIONS

This clinical comparison of conventional glass ionomer, resin-modified glass ionomer and resin composite cervical restorations in the xerostomic patient, has shown evidence of therapeutic efficacy of fluoridated materials on reduction of recurrent caries. No recurrent caries was evident in daily users of fluoride gel, whereas a material-dependent incidence of recurrent caries was seen in the fluoride non-user group. Recurrent caries reductions for glass ionomer and resin-modified glass ionomer relative to resin composite were greater than 80% in xerostomic patients not using topical fluoride supplementation. Fluoride-releasing restorative materials can provide an additional clinical approach in the overall disease management of the high caries-risk patient.

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Clinical Evaluation of a Resin-Modified Glass Ionomer Adhesive System: Results at Five Years

MJ Tyas • MF Burrow

Clinical Relevance

Fuji Bond LC performed very successfully as an adhesive for resin composite in non-carious cervical lesions over a five year evaluation period.

SUMMARY

One hundred non-carious, non-undercut cervical lesions were restored with Silux Plus or Estio LC and bonded with Fuji Bond LC. The restorations were evaluated yearly for retention and marginal discoloration. After five years, the overall retention rate was 96%. Of the 41 restorations examined at five years, five had clinically evident marginal discoloration.

INTRODUCTION

To satisfy esthetic requirements, the restoration of non-carious cervical lesions (NCCLs) is usually carried out with tooth-colored adhesive materials such as resin composite in conjunction with a dentin-bonding agent or with glass ionomer cement. In this way, there is no necessity to prepare mechanical retention in what is usually an inherently non-retentive lesion.

Dentin bonding agents have undergone major developments over the last 20 years. However, these developments have been so rapid that long-term clinical data on specific products are rarely available because of the regular introduction of "improved" versions. There is no doubt that current products are substantially more effective in retaining resin composite in NCCLs than their earlier counterparts (Tyas, 1994).

Glass ionomer cements, (GICs), particularly the self-cure types, have demonstrated excellent long-term retention in NCCLs (Matis, Cochran & Carlson, 1996), and the more recent resin-modified glass ionomers (RM-GICs) also show substantial promise in this application (Neo & Chew, 1996). However, RM-GICs, although retentive, have shown a deterioration in color, polish and marginal status after a number of years in the oral cavity (Gladys & others, 1999; Folwaczny & others, 2000; Brackett & others, 2001). A third available technique is the placement of GIC to replace the dentin, overlaid by a resin composite to replace the enamel (the "sandwich") technique. This technique was first proposed for NCCLs in 1977 (McLean & Wilson, 1977), using a self-cure GIC. These authors (McLean & Wilson, 1977) recommended that a thin "lute" of GIC should be left at the cervical (dentin) margin in order to avoid a resin-dentin interface, since at the time, the bonding of resin composite to dentin was tenuous. This technique was also described for an approximal amalgam restoration and was termed a "cervical lining" (McLean & Gasser, 1985).

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Fuji Bond LC (GC International, Tokyo, Japan) is a resin-modified GIC but is used in a similar way to a dentin-bonding agent in that it is thinly applied to the cavity walls and floor. Following photocuring, the resin composite is placed. Therefore, in some respect, it is similar to the recommendations of McLean (McLean & Wilson, 1977).

Previous papers by the authors have reported the one-year (Burrow & Tyas, 1998) and three-year (Tyas & Burrow, 2001) performance of Fuji Bond LC in retaining two resin composites (one hybrid and one microfil) in NCCLs. This paper reports the five-year performance.

METHODS AND MATERIALS

The details of the materials and methods have been described previously (Burrow & Tyas, 1998). Essentially, 100 NCCLs (19 by MJT; 81 by MFB) in 13 patients of mean age 60.5 years were restored. Lesions were cleaned briefly with a pumice/water slurry on a rubber cup, rinsed for approximately five seconds and dried with a short blast of air. An aqueous solution of 20% polyacrylic acid with 3% aluminum chloride (Cavity Conditioner; GC International) was applied to the lesion surface for 10 seconds, then washed off for five seconds with air/water spray. The lesion was dried briefly with an air stream and Fuji Bond LC was mixed and applied as thinly as possible with a brush and cured for 10 seconds with a photocuring light. The lesions were restored alternately with Silux Plus (3M Dental Products, St Paul, MN 55144, USA) or Estio LC (GC International) in bulk and photocured for 40 seconds. Following finishing and polishing using fine composite finishing diamonds and abrasive disks (Sofl Lex, 3M Dental Products) under water spray, a low-viscosity unfilled resin (Fuji Coat; GC International) was applied and photocured for 10 seconds.

The presence or absence of restorations was recorded at each recall and survival (life table) analysis was used to calculate retention rates. Photographs were taken of the initial lesions, the completed restoration (base line), and at six-months, one-year, two-year, three-year, four-year and five-year recalls. The photographs were used by one author (MJT) to assess marginal discoloration on a continuous linear rating scale of zero to eight (Tyas, 1994), where a value of approximately three or more generally represented the level at which esthetics might be compromised. The distribution of marginal discoloration scores was compared using chi-square analysis.

RESULTS

At the end of five years, seven of the original 13 patients had been lost to follow-up, representing a total of 26 Silux Plus and 29 Estio LC restorations. Distribution of restorations is shown in Table 1, and the cumulative retention rates can be seen in Table 2. After five years, 94% of the Silux Plus and 96% of the Estio LC restorations were retained, with an overall retention rate of 96%.

Distribution of the five-year marginal discoloration scores is given in Table 3. Five of the restorations examined at five years had a marginal discoloration score of ≥ 3, and there was no significant difference between Silux Plus and Estio LC (p=0.14). There were no instances of secondary caries.

DISCUSSION

The loss of half of the original patients to follow-up at five years was not unexpected. However, the consequent inability to evaluate 55% of the restorations was handled by using survival analysis, which is designed for this eventuality (Smales, 1991).

The mean age of patients in the study was 60.5 years, which is to be expected given the increasing frequency of NCCLs with age. Thus, the results of this study may not be applicable to those clinics with a predominance of younger patients. However, the efficacy of Fuji Bond

Table 1: *Distribution of Restorations*

	Upper Anteriors	Lower Anteriors	Upper Posteriors	Lower Posteriors	Total
Silux Plus	15	11	14	10	50
Estio LC	12	10	15	13	50
Total	27	21	29	23	100

Table 2: *Cumulative Assessment Data*

	Silux Plus			Estio			Overall
Interval	Lost	Unknown*	Cumulative Retention, %	Lost	Unknown*	Cumulative Retention, %	Cumulative Retention, %
0 – 1 y	2	2	96	0	3	100	99
1 – 2 y	0	2	96	0	1	100	98
2 – 3 y	1	0	94	0	0	100	97
3 – 4 y	0	15	94	1	15	97	96
4 – 5 y	0	7	94	0	10	97	96

**Restorations not examined as patients did not attend for recalls.*

Table 3: *Marginal Discoloration Scores at Five Years*

Score	Silux Plus	Estio LC
0	14	11
1	4	4
2	0	3
3	3	0
4	0	1
5	0	1
Unknown	29	30

Chi-square analysis indicated no significant difference between Silux Plus and Estio LC (p=0.14).

LC in this older age group in retaining resin composite in NCCLs is very evident. The loss rate at five years (96% overall) is similar to that of glass ionomer alone. For example, a two-year retention rate of 94% of a resin-modified glass ionomer (Fuji II LC; GC International) in NCCLs has been reported (Folwaczny & others, 2000). There do not appear to be any other clinical studies of Fuji Bond LC. In addition, the annual rate of loss of the two resin composite types appears to be reasonably constant, suggesting a stable bond to presumably sclerotic dentin.

The retention of Silux Plus (a microfil material) and Estico LC (a hybrid material) was essentially the same. The role of the elastic modulus of the restorative material has received some attention in the literature. One report (Heymann & others, 1991) reported a higher retention rate for microfine resin composites compared to hybrid composites in NCCLs when used with a dentin bonding agent. The proposed reason for this finding was that the low modulus microfine material flexed with the tooth during occlusal loading, whereas the high modulus hybrid material did not flex and was displaced from the cavity. However, this study used an older type of dentin bonding agent, and this may have had a significant influence on the results. More recent clinical studies using currently available dentin bonding agents have not confirmed these findings; that is, there was no effect of elastic modulus on retention (Browning, Brackett & Gilpatrick, 1999; Burrow & Tyas, 1999).

Bond strengths of resin composite to dentin mediated by Fuji Bond LC have been reported at 15.5 and 19.4 MPa (Gordan, Boyer & Söderhölm, 1998; Wilder, Swift, May & others, 1998). The bonding mechanism is probably ionic between the carboxyl group in the cement and the calcium component of dentin, and partly micromechanical by hybrid layer formation with the dentin collagen (Mitra, 1991; Saito, Tosaki & Hirota, 1999).

The marginal discoloration around some restorations may result from loss of the "lute" of Fuji Bond LC, although this is speculative. An appearance of a thin, white line around some restorations immediately post-placement was noted, but whether this correlates with the marginal staining at five years cannot be determined. The fact that the marginal discoloration occurred mainly in three patients suggested that patient factors may be relevant.

CONCLUSIONS

Fuji Bond LC was highly successful in retaining resin composite restorations in non-carious cervical lesions over five years.

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Comparison of Pulpal Sensitivity Between a Conventional and Two Resin-Modified Glass Ionomer Luting Cements

RJ Smales • MS Gale

Clinical Relevance

The use of a conventional or two resin-modified glass ionomer luting cements has been associated with less post-cementation tooth sensitivity to air blasts than was present pre-operatively. No significant differences in post-cementation sensitivity were found among the three cements tested.

SUMMARY

This clinical study compared handling and any short-term tooth sensitivity associated with using one conventional and two resin-modified glass ionomer cements marketed for luting gold and ceramometal crowns. The patient's response to a 10-second blast of air applied to the vital tooth was scored pre-operatively and again within a one-to-four week post-cementation recall period. A score was also recorded for any sensitivity present at the time of cementation of the crown on the unanesthetized tooth. All three cements were easy to mix and place. Most of the teeth had no response to pulpal stimulation pre-operatively, associated with the cementation procedure or post-cementation, and there were no instances of severe sensitivity recorded. For all cements, the level of post-cementation tooth sensitivity was similar, and less than that found pre-operatively.

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INTRODUCTION

Several clinical studies have not supported the anecdotal belief that glass polyalkenoate (ionomer) luting cements are related to more post-cementation pulpal sensitivity than that experienced with zinc phosphate cements (Norman & Wright, 1986; Johnson, Powell & DeRouen, 1993; Bebermeyer & Berg, 1994; Pameijer & Nilner, 1994; Kern & others, 1996). Long-term clinical studies of glass ionomer luting cements have also reported relatively few pulpal problems (Klausner, Brandau & Charbeneau, 1989; Brackett & Metz, 1992; Metz & Brackett, 1994; Jokstad & Mjör, 1996), especially when the dentin smear layer was left intact (Metz & Brackett, 1994). Possible causes of reported pulpal sensitivity have been suggested (Johnson & others, 1993; McComb, 1996).

More recently, autopolymerizing resin-modified glass ionomer luting cements have been introduced. They have superior physical properties, adhesion and reduced solubility when compared with conventional glass ionomer luting cements (Tosaki & Hirota, 1994; Technical Product Profile, 1995; Diaz-Arnold, Vargas & Haselton, 1999). Although several of the resin-modified luting cements have been described (McComb, 1996), little is known regarding their clinical behavior. There have been several anecdotal reports of the bulk fracture of all-porcelain restorations cemented with these materials (Reality Now, 1995 & 1996; Clinical Research Associates, 1996). Anecdotal and survey reports have also noted that there appears to be little post-cementation sensitivity associated with resin-modified cements (Clinical Research Associates, 1996; Christensen, 1997a & 1997b). Because this finding requires verification, this study clinically evaluated the handling and any short-term tooth sensitivity associated with using one conventional and two auto-polymerizing resin-modified glass ionomer luting cements.

METHODS AND MATERIALS

Details of the three hand-mixed luting cements used are shown in Table 1. New Fuji I is an improved conventional glass polyalkenoate (ionomer) cement (Tosaki & Hirota, 1994) that consists of a fluoroaluminosilicate glass powder and a liquid copolymer of polyacrylic and itaconic acids, and water. Vitremer Luting Cement is a resin-modified glass ionomer material (Technical Product Profile, 1995), which is a modification of Vitremer glass ionomer restorative material. Vitremer Luting Cement is now marketed as RelyX Luting cement. The powder consists of a fluoroaluminosilicate glass with a microencapsulated potassium persulfate and ascorbic acid catalyst system that provides initiation for polymerization. The liquid is an aqueous solution of hydroxyethylmethacrylate (HEMA), tartaric acid and polycarboxylic acid modified with pendant methacrylate groups. New Fuji I and Vitremer Luting Cement are used without a tooth conditioner or bonding agent. Fuji DUET resin-modified glass ionomer cement consists of a powder containing a fluoroaluminosilicate glass and catalysts mixed with a liquid containing polyacrylic acid, HEMA, tartaric acid and water. The cement was marketed subsequently as Fuji PLUS. Fuji DUET Conditioner contains citric acid and ferric chloride and is used first to increase bond strength and seal the dentinal tubules. All three cements are recommended by their manufacturers for luting metal based crowns.

Adult patients who attended the Prince Philip Dental Hospital and required placement of gold or ceramometal crowns on tooth preparations in non-mobile, asymptomatic vital teeth were selected for the study. Pre-operative radiography and pulp testing were undertaken to demonstrate that selected teeth had vital pulps. The requirement of the study was to have approximately equal numbers of crowns luted using each cement and New Fuji I as a control material. Crowns were cemented on 88 teeth. There was no attempt to standardize the selection of patients or tooth types, apart from requiring the presence of opposing teeth and, where possible, using both cement types in the same patient. Patients were unaware of the cement used. Junior house dental officers who graduated at The University of Hong Kong undertook the clinical procedures. Training was given to these clinicians regarding the research protocol, data collection, tooth sensitivity testing and handling of the cements.

Prior to crown preparation, each vital unanesthetized tooth was subjected to a 10-second blast of compressed air from the triple syringe held against the facial surface of the crown. Care was taken to shield the adjacent teeth, using cotton rolls and fingers. Sensitivity was rated as either none (no response), mild (slight response), moderate (obvious response) or severe (could not tolerate). The same test was repeat-

Table 1: *Luting Cements Used in the Study*

Material	Manufacturer	Batch/Expiry Date
New Fuji I[1] (P:L ratio 1.8:1.0)	GC Corporation, Tokyo 174, Japan	240541/1997-05
Fuji DUET[2] (P:L ratio 2.0:1.0)	GC Corporation, Tokyo 174, Japan	170461/1998-04
Vitremer Luting Cement[3] (P:L ratio 1.6:1.0)	3M ESPE, St Paul, MN 55144	19941213/1996-12

[1]Refined or reformulated Fuji I. Subsequently marketed as [2]Fuji PLUS, and [3]RelyX Luting cement. P:L ratio = Powder to Liquid ratio.

Table 2: *Handling Characteristics of the Cements Used for Single Crowns*

Characteristic	New Fuji I	Fuji DUET	Vitremer LC
Consistency of mix	Acceptable	Acceptable	Acceptable
Volume of mix	Sufficient	Sufficient	Sufficient
Working time	Acceptable	Acceptable	Acceptable
Setting time	Acceptable	Acceptable	Acceptable
Snap set present	Yes	Yes	No
Rebound on seating	No	No	No
Ease of clean up when set	Good	Difficult	Good
Manufacturer's directions	Good	Acceptable	Acceptable
Overall assessment	Good	Acceptable	Good

ed at the one-to-four week post-cementation recall. The sensitivity response of the patient associated with the crown cementation procedure on the unanesthetized vital tooth was also recorded as either none, mild, moderate or severe, using the same criteria as before. However, no air blast was used. Any salivary contamination that occurred during cementation was noted and any foundation or core that was placed in the tooth.

Conventional gold and ceramometal crown preparations were cut using diamond points in high-speed handpieces with an air/water spray. Ultrapak knitted cords with Astringedent hemostatic solution (Ultradent, South Jordan, UT 84095, USA) were used as required to achieve gingival retraction. Impressions were taken using President (Colténe/Whaledent, Mahwah, NJ 07430, USA) addition cured silicone material. Provisional crowns were made using Trim II (Harry J Bosworth, Skokie, IL 60076, USA) acrylic resin and were cemented with Temp-Bond (SDS/Kerr, Orange, CA 92667, USA) zinc oxide and eugenol temporary cement. All restorations were fabricated on die spacer-relieved stone dies at the Prince Philip Dental Hospital. The quality of the dies and completed crowns was approved by designated staff. The crowns were usually delivered within two weeks of taking the impressions. The three cements were used according to the manufacturers' instructions; the dentin smear layer was left intact except when using Fuji DUET Conditioner, and care was taken not to dessicate the teeth. New Fuji I and Vitremer Luting Cement were allowed to set hard before excess material was removed. Excess Fuji DUET cement was removed from the crown margins before the material was fully set. The clinical handling of the luting cements was evaluated using a comprehensive questionnaire.

The distribution of patients, teeth, foundations, crown types, luting cements and tooth sensitivity responses were analyzed using Prism 2.0 (GraphPad Software, San Diego, CA 92121, USA). Statistical significance was set at the 5% probability level.

RESULTS

Table 2 summarizes the handling characteristics of the three luting cements. All materials were easy to mix and load (especially the two Fuji cements), and allowed for full seating of the crowns. However, excess Fuji DUET cement required prompt removal from the crown margins because of the difficulty in later removing the fully set material.

There were 24 male and 26 female patients with a mean age of 43.5 ± 15.7 (SD) years. There were no statistically significant differences in distributing the three luting cements by gender or by crown type, but there were significantly fewer foundations associated with the New Fuji I cement, Table 3. There were no significant differences in distribution of the three cements among molar, premolar and anterior teeth (p=0.08). Eighteen of the 88 vital teeth had been restored with amalgam, and seven had received resin composite as a foundation. Apart from one gold crown placed on a premolar, the other 24 gold crowns were placed on molar teeth. There were relatively more ceramometal crowns placed on anterior and premolar teeth than on molars (p<0.0001). This was expected for esthetic reasons. Relatively more foundations were placed in molars than in the other teeth (p=0.04), but there was no significant difference in the presence or absence of foundations between the two crown types (p=0.19).

Most of the vital teeth had no response to air blasts by patients either pre-operatively or during post-cementation testing of the crowns, and no teeth were recorded as having severe sensitivity at any time. The pre-operative tooth sensitivity recorded is shown in Table 4. Significantly more teeth that had crowns cemented subsequently using Vitremer Luting Cement showed moderate pre-operative sensitivity (p=0.03).

The tooth sensitivity status at the time of crown cementation procedure is shown in Table 5. Significantly more teeth showed mild sensitivity (46.7%) associated with Vitremer Luting Cement (p=0.003). However, moderate sensitivity was less frequent for Vitremer Luting Cement at the time of crown cementation (6.6%) than was present to air blast pre-operatively (20.0%).

Table 3: *Distribution of Cements by Gender, Crown Type and Foundation*

	Gender		Crown Type		Foundation	
Material	Male	Female	Gold	Ceramo-metal	Present	Absent
Fuji I	10	18	7	21	3	25
Fuji DUET	11	19	7	23	13	17
Vitremer	11	19	11	19	9	21
(df=2)	χ^2=0.007, p=0.99		χ^2=1.546, p=0.46		χ^2=7.633, p=0.02	

Table 4: *Pre-Operative Tooth Sensitivity to Air Blast by Cement Type*

Material	**None (%)**	**Mild (%)**	**Moderate (%)**
New Fuji I	18 (64.3)	8 (28.6)	2 (7.1)
Fuji DUET	27 (90.0)	2 (6.7)	1 (3.3)
Vitremer LC	19 (63.3)	5 (16.7)	6 (20.0)
		χ^2=10.41, df=4, p=0.03	

Table 5: *Tooth Sensitivity at Crown Cementation by Cement Type*

Material	None (%)	Mild (%)	Moderate (%)
New Fuji I	22 (78.6)	4 (14.3)	2 (7.1)
Fuji DUET	27 (90.0)	0 (0.0)	3 (10.0)
Vitremer LC	14 (46.7)	14 (46.7)	2 (6.6)
		χ^2=21.190, df=4, *p*=0.003	

Table 6: *Post-Cementation Tooth Sensitivity to Air Blast by Cement Type*

Material	None (%)	Mild (%)	Moderate (%)
New Fuji I	23.(82.1)	5 (17.9)	0 (0.0)
Fuji DUET	25 (83.4)	3 (10.0)	2 (6.6)
Vitremer LC	24 (80.0)	4 (13.4)	2 (6.6)
		χ^2=2.546, d =4, *p*=0.64	

Table 7: *Comparison of Pre-Operative and Post-Cementation Tooth Sensitivity*

	Pre-Operative	
Post-Cementation	None	Mild/Moderate
None	57	15
Mild/Moderate	7	9
McNemar χ^2=2.227, df=1, *p*>0.10		

The one-to-four week post-cementation tooth sensitivity status is shown in Table 6. There were no statistically significant differences among the three luting cements (*p*=0.64). Three teeth with occlusal traumatism were moderately sensitive initially, but this problem resolved over a period of weeks following occlusal adjustments. One other tooth that showed moderate sensitivity was associated with saliva contamination during crown cementation. This sensitivity also resolved after some weeks. These were the only four instances where patients stated that they had experienced some post-cementation discomfort. There was no association between post-cementation sensitivity and the presence or absence of foundations (*p*=0.61), the crown type (*p*=0.91) or the tooth type (*p*=0.53).

Table 7 compares the pre-operative with the post-cementation tooth sensitivity. Although there was a strong trend after one-to-four weeks towards reduced post-cementation sensitivity, this was not statistically significant (*p*>0.10).

DISCUSSION

All three luting cements were easy to mix and place. However, if Fuji DUET was allowed to set completely, it became difficult to remove the excess cement from the margins of the crowns, Table 2. The manufacturer of the reformulated New Fuji I claims that it is easier to mix and use and that it sets faster than the original Fuji I luting cement.

Pulpal sensitivity to a 10-second air blast was generally recorded as being absent or mild. There were relatively few instances of moderate sensitivity and no severe sensitivity was recorded (Tables 4-6). The 17.9% mild post-cementation sensitivity response related to New Fuji I within one-to-four weeks is similar to the 19.0% response found for Ketac-Cem (3M ESPE, D-82229 Seefeld, Germany) within two weeks (Johnson & others, 1993). In clinical trials, patient responses following the use of glass ionomer cements have reported relatively low and similar incidences of post-cementation sensitivity to zinc phosphate cement (Norman & Wright, 1986; Pameijer & Nilner, 1994; Bebermeyer & Berg, 1994; Kern & others, 1996).

In this study, there was relatively mild tooth sensitivity at the time of crown cementation for Vitremer Luting Cement compared to the other two cements (Table 5). However, pre-operatively, relatively more teeth were moderately sensitive to air blasts before the subsequent use of Vitremer Luting Cement than prior to using the other two cements (Table 4). There was no statistically significant difference among any of the luting cements for pulpal sensitivity to air blasts within the one-to-four week post-cementation period (Table 6). Although some anecdotal information suggests that most instances of post-cementation sensitivity to conventional glass ionomer cements occur within one week (Klausner & others, 1989), clinical trials have evaluated early post-cementation sensitivity at one week (Bebermeyer & Berg, 1994; Pameijer & Nilner, 1994: Jokstad & Mjör, 1996), two weeks (Johnson & others, 1993) and four weeks (Kern & others, 1996). In this study, 46% of the patients were reviewed at one week, 22% at two weeks, 18% at three weeks and 14% at four weeks.

Although not statistically significant, comparing the pre-operative with post-cementation tooth sensitivity status showed a much improved response, which may, in some instances, have resulted from the crowns that covered previously-exposed sensitive root dentin (Table 7). Avoiding occlusal traumatism by carefully adjusting the crowns at the time of their cementation may have further reduced any post-cementation sensitivity. The occurrence of post-cementation sensitivity recorded in this study, although generally slight, may also have been related to the relatively short laboratory turnaround time—generally less than two weeks (Pameijer & Nilner, 1994). There would have been little time for any secondary dentin to form in response to tooth preparation.

Care was taken to avoid pulpal insults during tooth preparation and cementation of the crowns. The prepared teeth were not allowed to desiccate and the dentin smear layer was left intact, except when using Fuji DUET Conditioner that contained ferric chloride used to occlude the dentin tubules. Care was also taken to use the correct proportion and mix of cements and to avoid saliva contamination during cementation of the crowns. Attention to these details was possibly more important to avoid post-cementation sensitivity than the actual cement used.

CONCLUSIONS

Using a conventional glass ionomer cement (New Fuji I) or two resin-modified glass ionomer cements (Vitremer Luting Cement and Fuji DUET) for cementation of gold or ceramometal crowns on vital teeth resulted in less post-cementation sensitivity to air blasts within a one-to-four week recall period than was present pre-operatively. Most teeth showed no post-cementation sensitivity, and there were no statistically significant differences found among the three luting cements.

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Laboratory Research

Effect of Self-Etching Primer vs Phosphoric Acid Etchant on Bonding to Bur-Prepared Dentin

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M Nakajima • J Tagami

Clinical Relevance

The influence of the type of bur used to prepare dentin on resin-dentin bond strength depends upon the type of adhesive systems used. To obtain good adhesion to dentin for any adhesive system, the smear layer should be completely removed with a conditioner.

SUMMARY

This study evaluated the effect of dentin conditioner on tensile bond strength to dentin prepared with different types of burs. A self-etching primer system, Mac-Bond II (MB, Tokuyama Dental) and a phosphoric acid etching system, Single Bond (SB, 3M) were used for conditioning. Twenty-four extracted intact human molars were ground flat to expose occlusal dentin. After the dentin surfaces were polished with #600 SiC paper, the teeth were randomly divided into a control group and three experimental groups according to the bur grits used: #600 SiC paper only as the control, fine cut steel bur (SB600), cross cut steel bur (SB703) and regular grit diamond bur (DB) mounted in a dental handpiece utilizing water cooling. The dentin surfaces were treated with one of two adhesive systems, then composite buildups were done with Clearfil AP-X (Kuraray Medical). After soaking the bond specimens for 24 hours in 37°C water, multiple vertical serial sections (0.7 mm thick, 7-8 slices per one tooth) were made, trimmed to form an hour-glass shape with a 1.0 mm² cross-section and tensile bond strengths were determined at a cross-head speed of 1 mm/minute. Statistical analysis was made using one and two-way ANOVA and Fisher's PLSD test ($p<0.05$). Six additional molars were used for SEM observations of the dentin surfaces of each group before and after treatment with the self-etching primer of MB, and another four teeth were used to observe the resin-dentin interface of each group of SB. Using MB, the DB group produced the lowest tensile bond strength (TBS) among the groups that received bur preparation, and there were no statistical differences among SB600, SB703 and the control. For SB, the TBS of SB703 was the highest, and there were no statistical differences among the other groups and the control. The influence of the method used to pre-

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pare dentin for micro-tensile bond strength testing was dependent on the adhesive system used.

INTRODUCTION

After mechanical preparation of the cavities with any dental instrument such as a bur, an amorphous layer of organic and inorganic debris, the so-called smear layer is created over the tooth surface (Pashley, 1984). This layer covers the dentin surface, adheres weakly to the underlying dentin, occludes the entrance of the dentinal tubules and cannot be removed by ordinary water spray. It is well known that the quality and the quantity of the smear layer varies widely according to the way it is created (Eick & others, 1970; Gilboe & others, 1980). Although the smear layer diminishes the dentin permeability, it may impede the direct contact of the bonding material with the dentin (Pashley, 1984; Nakabayashi & Pashley, 1998). It has been reported that the bond strength to dentin depends on characteristics of the smear layer created by a rotary cutting instrument on the dentin surface (Tagami & others, 1991; Watanabe, Saimi & Nakabayashi, 1994a; Toida, Watanabe & Nakabayashi, 1995; Sekimoto, Derkson & Richardson, 1999). To obtain good adhesion to dentin, the smear layer should be removed or modified with conditioners such as acidic solutions (Toida & others, 1995).

The authors previously reported the effects of different types of burs on dentin bond strengths of three self-etching primer bonding systems, Clearfil Liner Bond 2, Clearfil Liner Bond 2V and Clearfil SE Bond (Kuraray Medical) (Ogata & others, 2001b). High bond strengths produced by these bonding systems have been reported in *in vitro* studies that used #600-grit silicon carbide abrasive papers for dentin surface preparation (Harada & others, 2000; Ogata & others, 2001a). Most laboratory bonding studies are done using silicon carbide abrasive papers to prepare the dentin surfaces, whereas different cutting instruments such as diamond or steel burs are routinely used in the clinic. In our previous study, however, the high bond strength obtained by using #600 grit SiC paper decreased when the dentin surfaces had been prepared with burs, particularly when they were cut using a regular-grit diamond bur (Ogata & others, 2001b). The self-etching primers produced less etching because of their relatively high pH (1.5-3.0, information from the manufacturer), when compared with 32-37% phosphoric acid pHs (-0.43 to 0.02), (Perdigão & others, 1996). When the dentin surfaces were prepared by burs, some of the smear layers could not be completely removed by self-etching primers due to their weak acidity. This may have compromised demineralization of the underlying dentin and further penetration of the bonding resin into the demineralized dentin. The authors concluded that this may be the reason why bond strengths to dentin prepared with burs decreased, especially for the group prepared with diamond burs (Ogata & others, 2001b). On the other hand, dentin bond strength has been reported to be high and stable when the smear layer created in a variety of ways was removed with stronger etchants such as a phosphoric acid or a citric acid etchant (Tagami & others, 1991; Toida & others, 1995). Thus, information on the comparative effects of another self-etching primer vs 35% phosphoric acid on bonding to bur-prepared dentin is desirable to determine appropriate clinical use of dentin bonding systems.

This study evaluated the effect of dentin conditioners on tensile bond strength to dentin prepared with different types of burs using a self-etching primer system and a phosphoric acid etching system.

METHODS AND MATERIALS

Figure 1 illustrates the specimen preparation method used for tensile bond strength testing and SEM observation. This was the same method used in our previous study (Ogata & others, 2001b). Twenty-four frozen, extracted caries-free human third molars were thawed and used for microtensile testing (Sano & others, 1994). The occlusal enamel was removed perpendicular to the long axis of the tooth by means of a model trimmer under running water, and a flat dentin surface was polished with #600 SiC abrasive paper under running water. The teeth were then divided into four groups (six teeth for each group) according to bur types and grits (Table 1)—1: fine cut 12-blade tapered fissure steel bur (SB600 group), 2: cross-cut tapered fissure steel bur (SB703 group), 3: regular grit diamond bur (the average diamond particle size: 100 µm) (DB group), 4: Control surface abraded with 600 grit SiC paper (AP#600 group). Dentin surfaces of the SB600 and SB703 groups were cut with the respective steel burs that were mounted in a straight micromotor handpiece

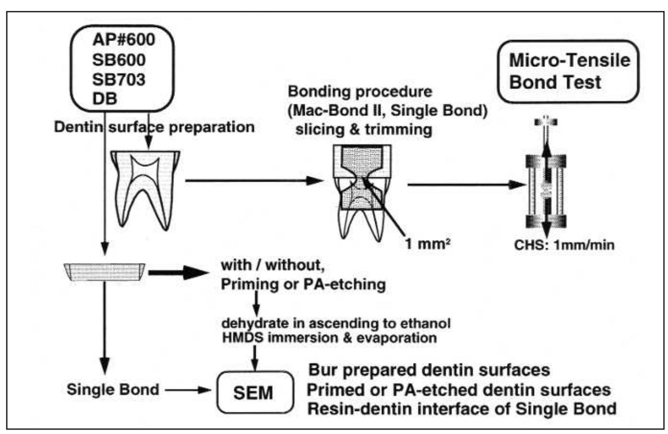

Figure 1. *Schematic showing the specimen preparation method used for tensile bond strength testing, SEM observations of the dentin surfaces prepared with burs or abrasive paper and SEM observation of the dentin surfaces of each group treated with the self-etching primers. CHS=cross-head speed.*

(Intramatic Lux2 10LN, KaVo, Germany) at 2,000 rpm. Teeth in the DB group were cut with a diamond bur that was mounted in a dental turbine (Super Torque Lux2 640B, KaVo, Germany) at 100,000-120,000 rpm. The teeth were prepared by the same operator by making 30 passes with the bur across the dentin surface under copious air-water spray until the uniform scratches by each bur covered the entire dentin surface. For the AP#600 group, teeth were prepared by use of 20 strokes of 15 cm length on #600-grit SiC paper under running water with hand pressure.

After preparation of the dentin surfaces, all teeth were treated with a self-etching primer system, Mac-Bond II (Tokuyama Dental, Tokyo, Japan), or a one-bottle wet bonding system using 35% phosphoric acid etchant, Single Bond (3M, St Paul, MN 55144, USA), according to the manufacturers' instructions (Table 2). After each adhesive resin was light-cured, a resin composite was built up using four layers of Clearfil AP-X (Kuraray Medical Co, Ltd, Tokyo, Japan) to a height of 5 mm to ensure sufficient bulk for the microtensile bond test (Sano & others, 1994). Each layer was light cured for 20 seconds. Specimens were then stored in 37° water for 24 hours.

The resin-bonded teeth were then serially sectioned into 7-8 slices parallel to the long axis of the tooth, approximately 0.7 mm thick, using a low-speed diamond saw (Leitz 1600 Microtome, Leica Instruments GmbH, Heidelberg, Germany) under water cooling. The bonded areas were isolated using a superfine diamond bur (c16ff, GC Ltd, Tokyo, Japan) to create an hourglass configuration with a cross-sectional area of approximately 1 mm^2. The final width and thickness of the bonded area were measured using a digital caliper to adjust the raw bonding data to an equalized bond/1 mm^2. The specimens were then attached to a testing device (Bencor-Multi-T, Danville Engineering Co, San Ramon, CA 94583, USA) with a cyanoacrylate adhesive (Zapit, Dental Ventures of America, Corona, CA 91720, USA), which in turn, was placed in a table-top material tester (EZ-Test, Shimadzu Co, Kyoto, Japan) for tensile testing at a cross-head speed of 1 mm/minute (Sano & others, 1994) (Figure 1). After the bond strengths were measured, all of the specimens were inspected visually and microscopically (x20, Dentcraft Dent-Optics DX, Yoshida, Tokyo, Japan), to determine the modes of failure. Representative samples were also observed using a scanning electron microscope (JXA-840, JEOL, Tokyo, Japan) to confirm the accuracy of the visual inspection.

Statistical analysis of the tensile bond strengths was performed using one-way and two-way ANOVA and Fisher's PLSD test at 95% level of confidence.

Six additional third molars were used for SEM observation of the dentin surfaces prepared with burs or abrasive paper before and after treatment with Mac-Bond II self-etching primer or 35% phosphoric acid of Single Bond, using a low-speed diamond saw (Leitz 1600 Microtome, Leica Instruments GmbH). Flat dentin discs were cut with a thickness of approximately 1 to 1.5 mm perpendicular to the long axis of the tooth from the mid-coronal part of the teeth. Each disk was cut into halves, and three half-discs were used for each group (SB600, SB703, DB or

Table 1: *Identification of Groups by Dentin Surface Preparation*

Group	Method for Preparation	Manufacturer	rpm
AP#600	#600 silicon carbide paper	Marumoto Struers Tokyo, Japan	-
SB600	Fine cut tapered fissure steel bur, #600 (12 blades)	Hager & Meisinger, Dusseldorf, Germany	2,000 rpm
SB703	Cross cut tapered fissure steel bur, #703 (6 blades)	Dentech, Tokyo, Japan	2,000 rpm
DB	Diamond point, FG-Regular, #103 (average diamond particle size: 100 µm)	Shofu, Kyoto, Japan	100,000~120,000 rpm

Table 2: *Adhesive Systems Used for Bonding*

System	Ingredients	pH	Procedures	Manufacturer
Mac-Bond II				
Primer A	MAC-10, methacryloyloxyalkyl acid phosphate, isopropanol, acetone, water, accelerators	1.7(A+B)	a; b (20 seconds); c; d (10 seconds)	Tokuyama Dental, Tokyo, Japan
Primer B	isopropanol, water			
Bonding agent	MAC-10, BIS-GMA, TEGDMA, HEMA, photoinitiator			
Single Bond				
Etchant	35% phosphoric acid gel	0.6	e(15 seconds); f; g; h; d(10 seconds)	3M, St Paul, MN, USA
Adhesive	BIS-GMA, HEMA, polyalkenoic acid copolymer, ethanol, water, photoinitiator			

Procedures: (a) mix primer; (b) apply primer; (c) apply adhesive; (d) light-cure; (e) acid-etching; (f) rinse; (g) blot-dry; (h) apply two coats of adhesive

AP#600). Dentin surfaces were prepared with burs or silicon carbide paper as was done for the dentin bond strength measurement described above. For SEM observation of the degree of etching of these dentin surfaces, the surfaces of two of the three half-disks were treated with Mac-Bond II self-etching primer or the phosphoric acid of Single Bond. After each application time, the primer components were removed with a 50% acetone/water solution (Harada & others, 2000) and the phosphoric acid gel was removed with water. The third half-disk was used for observation of the unetched smeared surface. All specimens were then dehydrated in ascending grades of ethanol (50%, 75%, 95% and 100% for 30 minutes each) followed by immersion in hexamethyldisilazane [$(CH_3)_3SiNHSi(CH_3)_3$, HMDS, Pierce, Rockford, IL 61105, USA)] for 10 minutes, placed on a filter paper inside a covered glass vial and air dried at room temperature (Perdigão & others, 1995). The specimens were then gold sputter-coated and observed with a scanning electron microscope (JXA-840, JEOL, Tokyo, Japan) at an accelerating voltage of 10 KV.

For Single Bond, the resin-dentin interface of each group was also observed by SEM. Four flat dentin disks were prepared with burs or abrasive paper and treated with Single Bond. The resin-bonded samples were then sectioned into two halves parallel to the longitudinal axis of the tooth. Each specimen was embedded in epoxy resin (Epon 815, Nissin EM Co, Ltd, Tokyo, Japan), then the cut surfaces were ground with a series of increasingly finer silicon carbide abrasive papers and highly polished with diamond pastes (DP-Paste,P, Struers A/S, Denmark) (6 µm, 3 µm, 1 µm). The samples were subjected to 10% phosphoric acid treatment for three-to-five seconds (Gwinett & Kanca 1992; Sano & others, 1995). The specimens were rinsed with water for 15 seconds and treated with 5% hypochlorite solution for five minutes (Wang & Nakabayashi, 1991). After extensive rinsing with water, the treated specimens were air dried, gold-sputter-coated and observed with the SEM at 10KV. This was not done for specimens bonded with Mac-Bond II because the hybrid layers were so thin that differences between the groups by SEM could barely be seen.

RESULTS

Figure 2 and Table 3 show the microtensile bond strength (µTBS) results of each group. For Mac-Bond II, there were no statistically significant differences among the groups prepared with steel burs (SB600: 41.3±9.7 MPa; SB703: 38.4±10.6 MPa) and the control (AP#600: 37.9±11.8 MPa). The DB group of Mac-Bond II produced lower tensile bond strength than the groups that received steel bur preparation (DB: 32.3±8.4 MPa), and this group produced lower, although not significant, bond strength compared to the AP#600 group ($p>0.05$). For Single Bond, the SB703 group produced highest tensile bond strength (43.7±7.5 MPa), but there were no statistically significant differences among the other groups and the control (AP#600: 35.4±9.9 MPa; SB600: 34.1±9.7 MPa; DB: 37.6±8.1 MPa). Two-way ANOVA analysis revealed a statistically significant interaction between the bonding systems and the methods of dentin surface preparation ($p=0.0032$).

When visually inspected, most specimens showed interfacial adhesive failure. This was confirmed by light microscopic examination (x20). The representative micromorphology of the failure pattern was classified as mixed failures within dentin and bonding resin. There was no remarkable difference in the failure patterns among all the groups.

Scanning electron micrographs of each prepared dentin surface are shown in Figure 3. For Mac-Bond II, micrographs of the prepared dentin surface treated with the primer of each group are shown in Figure 4. For Single Bond, micrographs of the prepared dentin surface treated with phosphoric acid are shown in

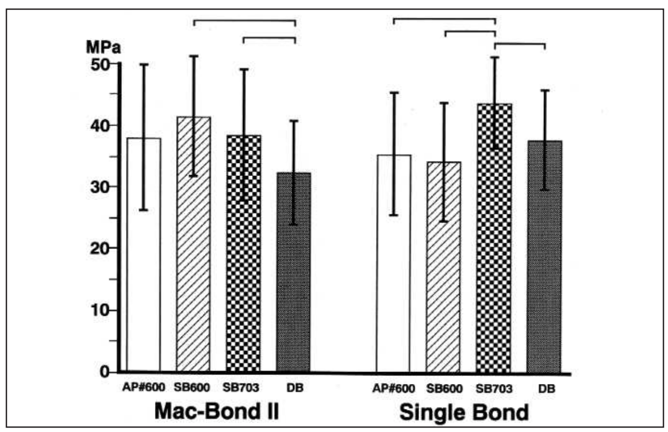

Figure 2. *Results of microtensile bond strengths for each group. Groups connected with horizontal lines are significantly different (*p*<0.05).*

Table 3: *Results of Microtensile Bond Strengths for Each Group (mean±SD) (MPa)*

	AP#600 (control)	SB600	SB703	DB
Mac-Bond II	37.9±11.8[ab] (n=23)	41.3±9.7[bc] (n=24)	38.4±10.6[bc] (n=21)	32.3±8.4[a] (n=25)
Single Bond	35.4±9.9[a] (n=22)	34.1±9.7[a] (n=22)	43.7±7.5[c] (n=21)	37.6±8.1[a] (n=24)

*(n): number of the slabs tested. Groups that are not significantly different are marked with the same superscript letter (*p*>0.05).*

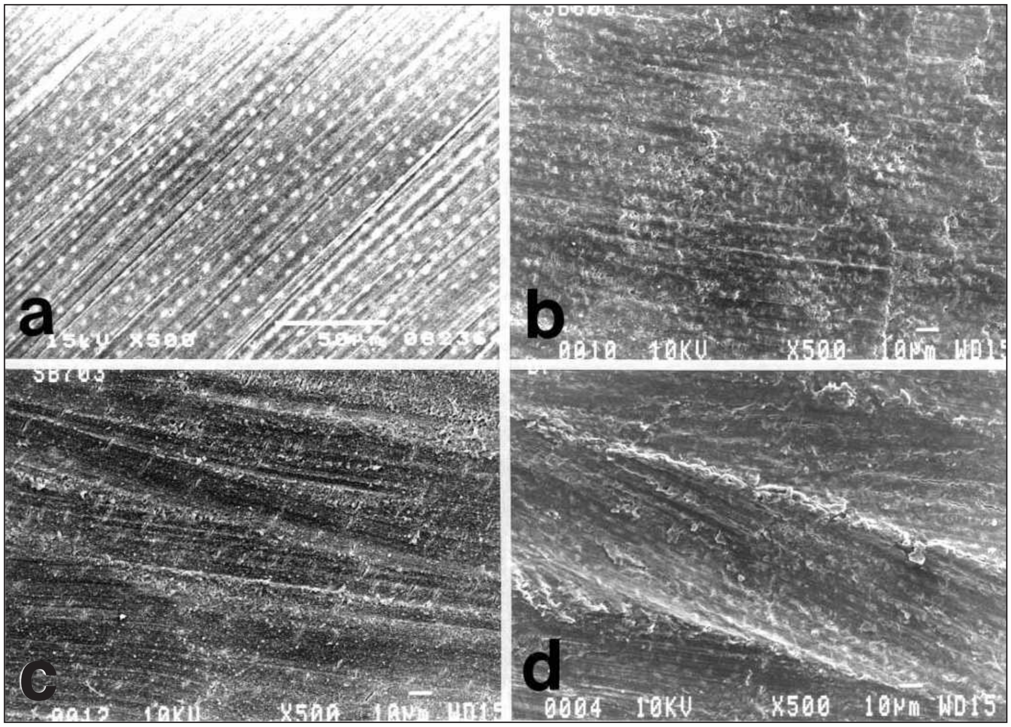

Figure 3. *SEM of the prepared dentin surfaces of each group a: AP#600 group; b: SB600 group; c: SB703 group; d: DB group. (Original magnification x500; bar : a = 50μm, b-d = 10 μm).*

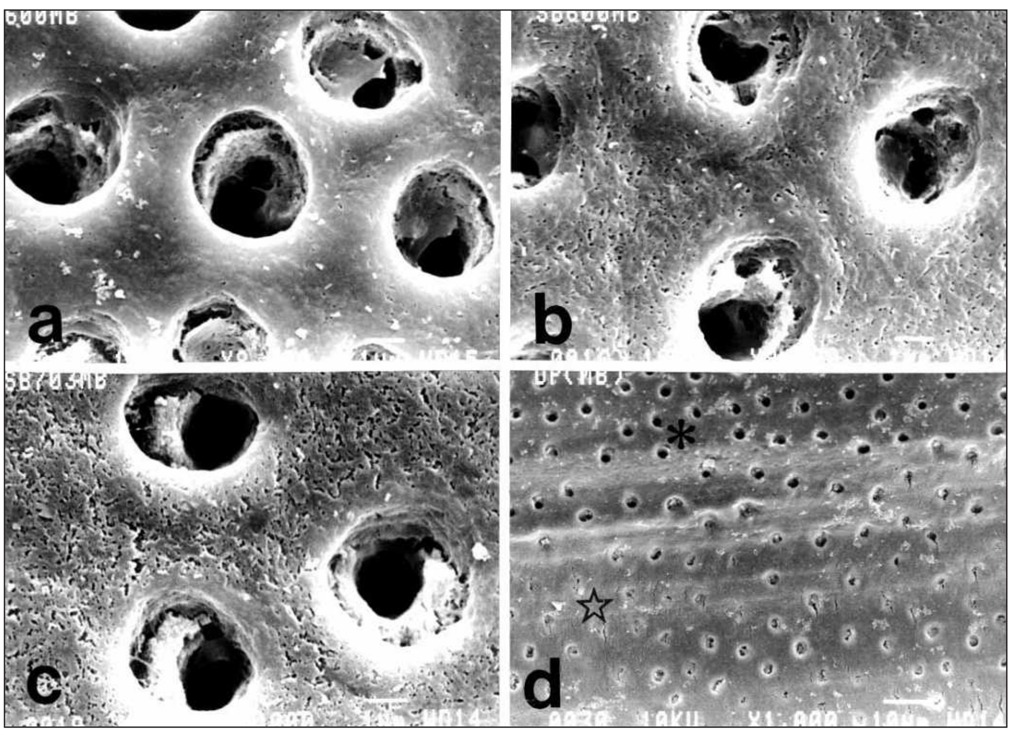

Figure 4. *SEM of MAC-BOND II primer treated dentin surfaces. a: AP#600 group; b: SB600 group; c: SB703 group; d: DB group. On the dentin surface of the DB group, there were areas without smear layer (marked by the asterisk) and areas with remnants of smear layer (marked by the star). (Original magnification: a-c=8000x, d=x1000; bar: a-c = 1 μm, d=10 μm).*

Figure 5 and the resin-dentin interface of each group is shown in Figure 6. For the groups AP#600, SB600 and SB703, the prepared dentin surfaces revealed many scratches left by the abrasive paper or burs, and the surfaces were completely covered with a smear layer. Dentinal tubules that were occluded by the smear plugs were also observed over the entire surface (Figures 3 a-c). SEM observation of the dentin surface of the DB group demonstrated that grooves left by the diamond bur were coarser than the other three groups (Figure 3d). A thick, irregular smear layer without any evidence of underlying dentinal tubules was seen on the top of the grooves, while dentinal tubules occluded by smear plugs could be observed at the bottom of the grooves (Figure 3d). For the AP#600, SB600 and SB703 groups of the Mac-Bond II primer treated surface, the smear layer on the dentin surface and the smear plugs in the dentinal tubules were removed. For these groups, the intertubular dentin and the peritubular dentin of the tubule orifices were slightly etched, and the edges of the dentinal tubules were clearly observed (Figures 4 a-c). For the DB group treated with Mac-Bond II, two primed, distinct zones that seemed to alternate were observed. In one zone, the smear layer and the smear plugs were removed, the intertubular dentin and the peritubular dentin were slightly etched and the edges of the dentinal tubules were clearly observed. In the other zone, the residual smear layer and smear plugs could be observed (Figure 4d). For all the Single Bond groups, the smear layer on the dentin surface and the smear plugs in the dentinal tubules were completely removed, and the open tubules without peritubular dentin and a fine collagen fibril network on the surface were observed after phosphoric acid etching (Figures 5ab). The resin-dentin interface of each group indicated no remarkable difference by altering the method of surface preparation (Figures 6a-d). For all groups, the thickness of the hybrid layer was about 3 µm, and the resin tags with a characteristic funnel shape could be observed (Figures 6a-d).

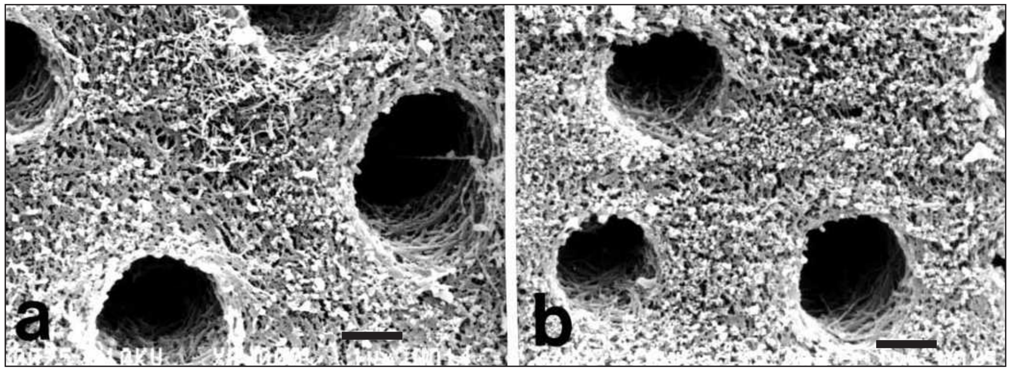

Figure 5. *SEM of 35% phosphoric acid etched dentin surface of Single Bond: a: AP#600 group; b: DB group. (Original magnification x8000; bar = 1 µm).*

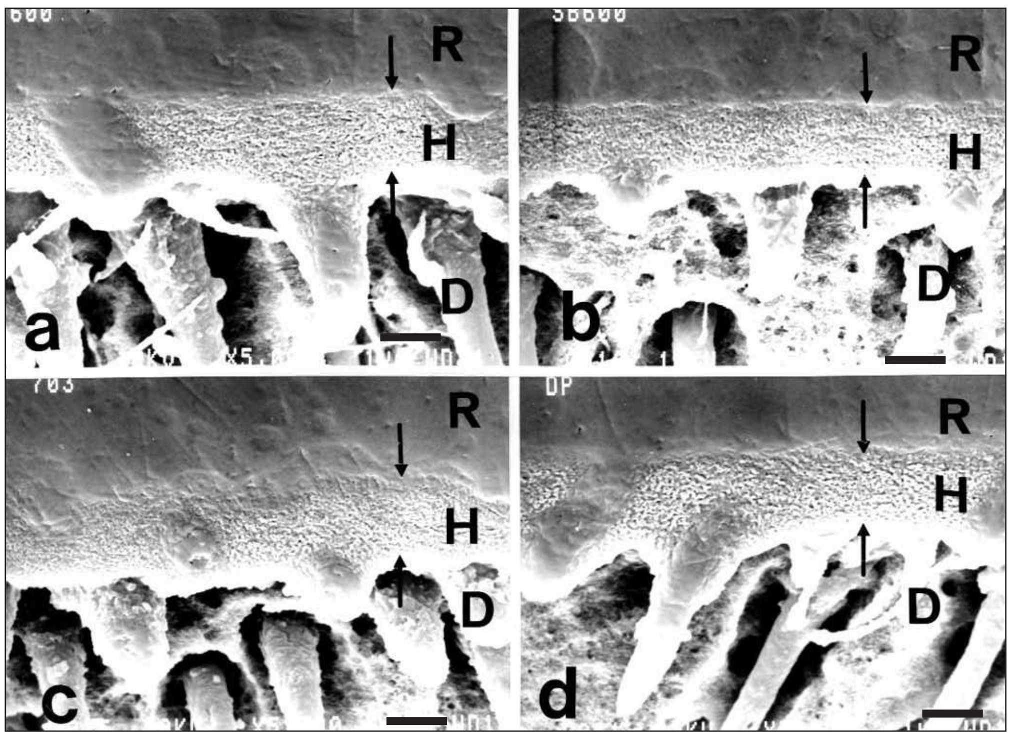

Figure 6. *SEM of the resin-dentin interface of Single Bond: a: AP#600 group; b: SB600 group; c: SB703 group; d: DB group R= bonding resin, H=hybrid layer, D=dentin. (Original magnification x8000; bar = 1 µm).*

DISCUSSION

The self-etching primers' acidic components demineralize through the smear layer and diffuse a short distance into the underlying dentin, resulting in the creation of a thin hybrid layer with strong bonds to dentin (Watanabe, Nakabayashi & Pashley, 1994b; Chigira & others, 1994). However, the self-etching primers do not etch as well as a 35% phosphoric acid etchant because of their relatively high pH (1.5 to 3.0 for self-etching primers, information from the manufacturer); -0.42 to 0.02 for phosphoric acid etchants, (Perdigão & others, 1996). Therefore, it is believed that bond strengths of self-etching primer bonding systems to dentin could be affected by differences in the quantity of residual smear layer left on the surface due to the weak acidity of self-etching primers. In our previous study that evaluated the effects of bur cutting using three self-etching primer bonding systems (Clearfil Liner Bond 2, Clearfil Liner Bond 2V and Clearfil SE Bond), the bond strengths of these systems to dentin decreased when the dentin surface had been prepared using burs, and particularly when it was cut using a regular-grit diamond bur (Ogata & others, 2001b). When the dentin surfaces were prepared by burs, some of the smear layer could not be completely removed by these self-etching primers due to their weak acidity. Thus, demineralization of the underlying dentin and further penetration of the bonding resin into the demineralized dentin could have been insufficient for optimal bond strength.

The current experimental design was the same as the previous study. The pH of the Mac-Bond II primer of this system is 1.7 (primer A+B, information from the manufacturer), which is almost the same pH as Clearfil Liner Bond 2. Nakaoki & others (1996) reported that the demineralization effect of Mac-Bond II primer was stronger than that of the Clearfil Liner Bond 2 primer. In this study, Mac-Bond II primer successfully removed the smear layer of the AP#600, SB#600 and SB#703 groups (Figures 4 a-c). For these groups, which had similar bond strengths, the smear layer on the dentin surface and the smear plugs in the dentinal tubules were removed. The intertubular dentin and the peritubular dentin of the tubule orifices were slightly etched, and the edges of the dentinal tubules were clearly observed. On the other hand, the DB group treated with Mac-Bond II primer produced the lowest tensile bond strength among the groups that received bur preparation (although it was not significantly lower than the AP#600 group). Mac-Bond II primer could not completely remove the entire smear layer and the smear plugs created by the regular-grit diamond bur. There were areas without smear layer and areas with remnants of smear layer on the dentin surface after primer treatment (Figure 4d). SEM observations of the DB group's dentin surface demonstrated that grooves left by the bur were coarser than those seen in the other groups. An irregular, thick smear layer without any evidence of underlying dentinal tubules was seen on the top of the grooves, while dentinal tubules occluded by the smear plugs could be observed at the bottom of the grooves (Figure 3d). The Mac-Bond primer could only partially remove the irregular thick smear layer (Figure 4d). Thus, demineralization of the underlying dentin and further penetration of the bonding resin into the demineralized dentin may have been limited. The peculiar structure of the DB-created smear layer might explain the decrease in bond strengths seen in this group.

Akimoto & others (1999) reported that the microtensile bond strength of the Liner Bond 2V and Clearfil SE Bond were not affected by dentin surface condition. They bonded to dentin surfaces prepared with #180 or #600-grit abrasive papers versus mirror-like surfaces of dentin. Tay & others (2000) also reported that the microtensile bond strength of Clearfil SE Bond was not affected by the various thicknesses of the smear layers created by #60-, #180- or #600-grit abrasive papers or an absence of smear layer. These conflicting reports may be reconciled if the characteristics of the smear layers created by bur cutting differ from those created by abrasive paper. High-speed burs may induce increases in thermal and mechanical stress. These stresses could affect underlying dentin. An abrading cutting instrument, such as a diamond bur, creates more frictional stress compared to a steel bur-type-cutting instrument. Selecting burs for cutting the dentin surface for a direct resin composite restoration is important to produce optimal bonding of Mac-Bond II to dentin. Cutting the dentin surface with regular grit diamond burs should be avoided or followed with finishing the cavity surface with steel burs. Clinically, access to a carious lesion is done with diamond or carbide burs, generally followed by removing the carious dentin with round steel burs (Fusayama, 1980). Mac-Bond II showed similar tensile bond strengths for the steel bur and abrasive paper control groups. Therefore, when using steel burs, relatively high-bond strengths could be expected for the clinical use of this system.

Tagami & others (1991) reported that the dentin bond strength of Clearfil Photobond was not affected by the different smear layers created by SiC paper or regular-grit diamond bur. Clearfil Photobond is a system that uses 37% phosphoric acid etchant and a light-curing bonding agent with the dry bonding technique. In this study, the negative effect of dentin surface preparation by burs was not found for Single Bond, which used the wet-bonding technique after 35% phosphoric acid etching. Due to the stronger demineralization effect of the phosphoric acid etchant (pH=0.6, Table 2), the smear layer and smear plugs were completely removed regardless of how the surface had been prepared (Figures 5a, b), and the resin-dentin interface of each group indicated no remarkable difference among the methods of surface preparation (Figures 6a-d). Toida & others (1995) evaluated the effect of different dentin smear layers created by various burs on the tensile bond strengths of two types of adhesive systems, using an experimental self-etching primer (aqueous solution of 20% Phenyl-P and 30% HEMA) or an acid etchant (3% ferric chloride in 10% citric acid). According to their study, the rough, thick smear layer created with burs should be removed with acid etching in order to obtain a more reliable, higher bond strength. The results of this study also support the efficacy of smear layer removal by strong acid etchants. For Single Bond, the selection of bur type for the dentin surface preparation is unimportant. On the other hand, a system that uses the wet bonding technique has other problems. Although wet bonding is an excellent idea, it is technique-sensitive in clinical situations because it is difficult to produce a uniform wet state on all prepared surfaces (Tay, Gwinnett & Wei, 1996), especially in large, complex-shaped cavity restorations. Self-etching primer systems are less technique-sensitive but give lower bonds to diamond bur created smear layers. Thus, care must be taken when placing a resin restoration depending on the type of adhesive system used. In this study, no attempt was made to deviate from the manufacturer's instructions. However, it is likely that higher or more consistent bond strengths could have been achieved using Mac-Bond II if multiple applications of primer had been used with continuous agitation (Ogata & others, 1999).

CONCLUSIONS

When using Mac-Bond II, the DB group produced the lowest tensile bond strength among the groups prepared with a bur, and there were no statistically significant differences among the SB600, SB703 and AP#600 groups. For Single Bond, bond strength of the

SB703 group was highest, and there were no statistically significant differences among the other experimental groups and the control. The influence of the method used to prepare dentin on tensile bond strength depends on the type of adhesive system used. For any adhesive system, in order to obtain optimum adhesion to dentin, the smear layer should be removed with a conditioner.

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Retention of Selected Core Materials to Zirconia Posts

D Edelhoff • JA Sorensen

Clinical Relevance

Various core materials and bonding methods are available for prefabricated zirconia posts. A proper combination of core material and adhesion method is critical to establishing stable retention to the post.

SUMMARY

Due to their favorable optical and mechanical properties, endodontic posts made of partially stabilized zirconia ceramic (ZrO_2-Y_2O_3) are a promising alternative to those made of metal. Zirconia posts can be combined with various tooth-colored core materials to increase the optical properties of a final esthetic restoration. For stability, a reliable bond between core material and the post should be generated.

This *in vitro* **study evaluated the retention of selected core materials to zirconia posts dependent on different surface treatments and bonding procedures.**

Two types of zirconia posts (CeraPost [CEP], Lemgo, Germany) and CosmoPost [COP], Ivoclar Vivadent, Amherst NY 14228, USA) were employed for the study. Ring-shaped cores were fabricated of either heat-pressed, zirconia-containing glass ceramic (IPS Empress Cosmo [EMC], Ivoclar Vivadent), highly-filled hybrid composite (Tetric Ceram [TEC], Ivoclar Vivadent) or an experimental, high-strength glass ceramic (OHSU-RWTH [EX], Ivoclar Vivadent). The core made of material EX was either directly heat pressed (EXP) or adhesively bonded (EXB) onto the post using a flowable composite. Prior to core application, the post surfaces were preconditioned by alumina abrasion (AA) or tribochemical silicoating and silanation (TCS). Specimens (10 per group) were stored in artificial saliva (pH 5.2) for 150 days. Storage time included 5,000 thermocycles (5/55°C per 30 seconds). Defect analysis was conducted visually using a light microscope and a fiber optic transillumination prior to the testing procedure. The loads required to separate post and core were determined by a push-out test. Following testing, the surfaces of the posts and core materials were evaluated in a scanning electron microscope (SEM).

There were no statistically significant differences between the separation loads of groups COP/AA/EMC, COP/TCS/TEC, CEP/AA/EMC and COP/AA/EXB. Group COP/AA/EXP showed significantly higher retention, but also the highest standard deviation and the highest number and

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diversity of severe defects in the core material prior to testing. Similar defects were detected in the group COP/AA/EXC. In group COP/TCS/TEC, where there were a lower number of minor defects, and in COP/AA/EMC and COP/AA/EMC, no defects were observed.

For both post systems tested with the combinations alumina abrasion/zirconia-containing glass-ceramc and tribochemical silicoating and silanation/highly-filled hybrid composite, a reliable retention was achieved. The use of the experimental high-strength glass ceramic as a core material is contraindicated due to a discrepancy in the coefficient of thermal expansion to the zirconia-post.

INTRODUCTION

With the increasing use of esthetic restorative materials with greater translucency, the requirements for the restoration of endodontically-treated teeth have changed. Metal posts are most commonly used due to their excellent physical properties. However, their dark, opaque appearance can cause discoloration of the tooth and adjacent tissues and compromise the light scattering properties of the restoration (Meyenberg, Lüthy & Schärer, 1995). In addition, corrosive problems with some metal-alloys used for posts have been reported, causing a negative side effect on the surrounding tissues (Arvidson & Wróblewski 1978; Wu & others, 1998). In recent years, numerous approaches were undertaken to avoid these problems by using various all-ceramic systems in anterior teeth (Kern & Knode, 1991; Mutobe, Maruyama & Kataoka, 1995). Considering functional chewing forces (Helkimo & Ingervall, 1978), the clinical application of the majority of these systems has been limited due to insufficient strength (Kern, Pleimes & Strub, 1995, Leibrock & others, 1996).

As a substructure material, zirconia ceramic shows the highest fracture toughness, a very high Weibull modulus and extremely high flexural strength (Maier, 1995). Zirconia offers superior mechanical reliability (Cales, Stefani & Lilley, 1994; Ichikawa & others, 1992) and a growing range of applications (Meyenberg & others, 1995; Sjolin, Sundh & Bergmann, 1999; Studer, Wohlwend & Schärer, 1996). The restoration of endodontically-treated teeth with zirconia posts, combined with various translucent core materials, is a promising new perspective when superior esthetics are of primary interest. Due to the dentin-like translucency of zirconia ceramics, the optical properties of the restored teeth have been greatly improved (Edelhoff & Sorensen, 2001). The most common technique is the direct application of a composite material as a core. For the indirect technique, an individual ceramic core is fabricated separately in the laboratory and it is later intraorally bonded onto the post (Koutayas & Kern, 1999). One available system offers a corresponding glass-ceramic (Schweiger & others, 1999) that is directly heat-pressed onto the zirconia post (Kakehashi & others, 1998; Sorensen & Mito, 1998).

To resist the oral environment and masticatory forces, it is critical to establish a durable bond between the core and the post material. This includes an effective surface treatment of the zirconia ceramic. Hydrofluoric acid etching of zirconia ceramics is ineffective in generating a microretentive pattern (Dérand & Dérand, 2000; Kern & Wegner, 1998). However, various alternative techniques have been reported to generate a durable resin bond to zirconia ceramics (Dérand & Dérand, 2000, Edelhoff & others, 2000a; Göbel, Luthardt & Welker, 1998; Kern & Wegner, 1998).

This *in vitro* study evaluated the retention of selected core materials to zirconia posts with different surface treatments and bonding procedures.

METHODS AND MATERIALS

Two types of commercial, pre-fabricated zirconia posts were used in this *in vitro* study: the CeraPost ([CEP), ISO 90 corresponding to 1.76 mm diameter in the cylindrical upper part, Brasseler, Lemgo, Germany) and the CosmoPost ([COP), 1.7 mm diameter, Ivoclar Vivadent). To standardize specimens' geometry for the testing procedure, posts were shortened to a length of 14 mm by removing the conical portion.

Surface Treatments of the Zirconia Ceramic

According to findings of previous studies (Edelhoff & others, 2000a; Göbel & others, 1998; Kakehashi & others, 1998; Kern & Wegner, 1998), two surface treatments of the zirconia ceramic were employed:

- AA–Air abrasion (Aluminum oxide 110 µm grain size, 10 mm distance and vertical orientation of the nozzle, 13-second blasting time, 2.8 bar pressure)
- TCS–Tribochemical silicoating (modified Rocatec-method, 3M ESPE, Seefeld, Germany; Modification: *no* use of Rocatec-Pre, *only* blasting with Rocatec-Plus 110 µm grain size at 10 mm distance and vertical orientation of the nozzle, 13-second blasting time, 2.8 bar pressure, followed by 60-second silanation, Monobond S, Ivoclar Vivadent).

Core Materials

- EMC–Heat-pressed, zirconia-containing glass ceramic for the core of zirconia posts (IPS Empress Cosmo, Ivoclar Vivadent). The coefficient of thermal expansion (CTE) is adapted to the CTE of zirconia ceramic.
- TEC–Fine particle hybrid composite material (Tetric Ceram, Ivoclar Vivadent)
- EX–Experimental pressable high-strength glass ceramic (OHSU-RWTH, Ivoclar Vivadent). The core

Table 1: *Groups of Tested Core/Conditioning/Post Assemblies*			
Group	**Post System**	**Post Surface Treatment**	**Core Material**
1	Cosmopost	Alumina abrasion	Heat-pressed corresponding ceramic
2	Cosmopost	mod. Rocatec, Silanation	Composite
3	Cosmopost	Alumina abrasion	Heat-pressed experimental ceramic
4	Cosmopost	mod. Rocatec, Silanation	Cemented experimental ceramic
5	Cerapost	Alumina abrasion	Heat-pressed ceramic (Group 1)

made of EX was either directly heat-pressed (EXP) or adhesively bonded (EXB) onto the post.

The groups (n=10) of the tested core/conditioning/post assemblies are given in Table 1.

Specially designed silicon indices were employed to adjust the core material at a defined preconditioned post area. The shortened and pretreated posts were placed into those indices, where a resin (Pattern resin, GC, Tokyo, Japan) ring (Group 1, 3, 4 and 5) or the composite core Group 2) was added in defined position (Figure 1a). For groups 1, 3 and 5, the posts were invested with resin rings and after the burning-out process, the glass ceramics were directly pressed onto the preconditioned post areas (Figure 1b). In Group 4, the resin rings were removed from the post and invested and pressed separately. The final dimensions of the ring were adjusted on Carbimed paper sheets successively up to 600 grit (US Grain numbers, Carbimed paper sheets, Buehler, Lake Bluff, IL 60044, USA, corresponding to a 14 µm grain size) using the post with an adapter as an axis in a handpiece (K 9, KaVo, Biberach, Germany). The inner diameter of the separately fabricated ceramic rings made of material EX (Group 4) were 1.8 ± 0.02 mm. As EX represents an etchable glass ceramic, the inner surfaces of the rings were etched (20-second application of hydrofluoric acid: Ceramic-Etching gel, 4.5 weight-% HF, Ivoclar Vivadent) prior to bonding onto the pretreated post areas with a light-cured flowable hybrid composite (Tetric flow, Ivoclar Vivadent). Preliminary light curing was conducted for 40 seconds by a hand polymerization lamp (Model Densply the Max, Caulk, Milford, DE 19963, USA) followed by removing the excess with resin disks in a handpiece. The final light curing was conducted for 180 seconds in a laboratory device (UniXS, Heraeus-Kulzer Inc, South Bend, IN 46614, USA) to obtain standardized conditions and the same rate of conversion for all specimens. For the direct core material, a light-cured, highly-filled hybrid composite (TEC, Tetric Ceram Cavifil, Ivoclar Vivadent) was applied stepwise to the preconditioned post area using the index. Light curing was conducted in the same procedure as described for Group 4.

The dimensions prior to testing were 1.7 ± 0.02 mm in height and 3.76 ± 0.02 mm (CEP, group 5) or 3.7 ± 0.02 mm (COP, Group 1 to 4) in circumference/external diameter (Figure 2). All groups were stored for 150 days in a corrosive media (37°C, pH 5.2) of the composition: KCl 1.2 g, NaCl 0.89 g, $CaCl_2x\ 2H_2O$ 0.58 g, urea 0.1 g, lactic acid (90%) 10 g, completed with distilled water (aqua destillata) to 1.0 liter and adjusted with 1n NaOH to pH 5.2. The acid milieu was chosen to create chemical stress to the bonding system as it can clinically occur after sugar exposure (Geddes, 1975). In this storage period, 5,000 thermocycles were conducted in water (5°-55°C, 1 minute) for 84 hours.

Prior to the testing procedure, a light microscope (Nikon measurescope MM-11, Nikon, Tokyo, Japan) combined with fiber optic transillumination (T-Q/FOI-1, Techni-Quip Corp, El Segundo, CA 90245, USA) was used to analyze the quantity and quality of defects in the ring-shaped core material. The classification of the core defects is given in Figure 3. The specimens were seated in a specially designed steel box (stainless steel) similar to the testing device used in a previous investigation (Kakehashi & others, 1998) (Figure 4). Separation loads were determined in a universal testing device (Model,Type TT-B-L, Instron Engineering Co, Canton, MA 02021, USA) with a preload of 1 N and a cross head speed of 5 mm/minute. A vertical force was applied on the posts with a hardened steel rod up to the separation of the post-ring assembly.

The surfaces of the posts and inner cores were evaluated after separation in a scanning electron microscope (SEM).

Significant differences in separation loads ($p<0.05$) were determined by paired one-factorial analysis of variance (ANOVA) for Groups 1 to 4, and by unpaired one-factorial analysis of variance (ANOVA) for Groups 1 and 5.

RESULTS

Table 2: *Results of Defect Analyses Prior to the Testing Procedure*						
	Type of Defect					
Group	**A**	**B**	**C**	**D**	**E**	**F**
1	0	0	0	0	0	0
2	0	0	24	40	0	0
3	29	9	0	0	4	9
4	0	13	0	0	9	8
5	0	0	0	0	0	0

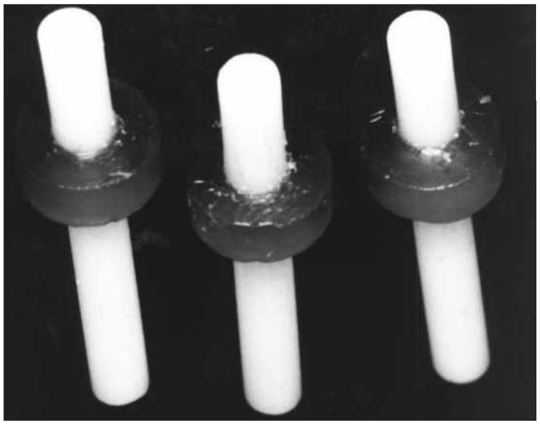

Figure 1a. *Shortened and pretreated posts with resin ring prior to heat pressing of the core ceramic.*

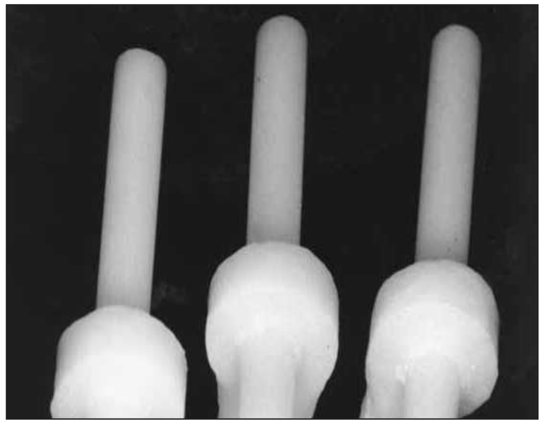

Figure 1b. *Posts with ring shaped glass-ceramic cores (EMC) after heat pressing.*

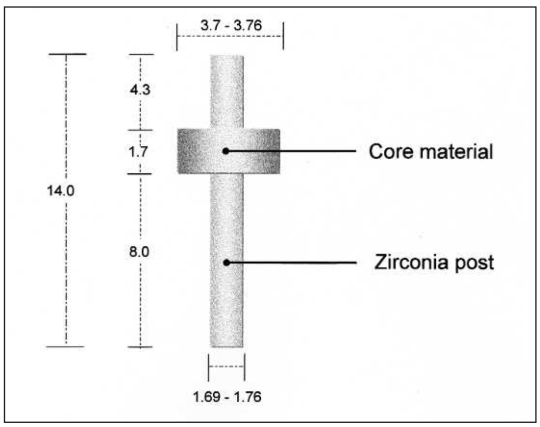

Figure 2. *Dimensions (in mm) of the specimens (post/core assembly).*

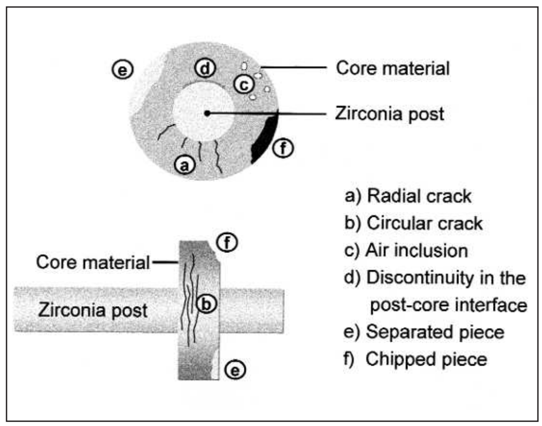

Figure 3. *Classification of core defects for optical analysis (Light microscopy and transillumination) of the specimens after storage in a corrosive media and thermocycling, prior to testing procedure.*

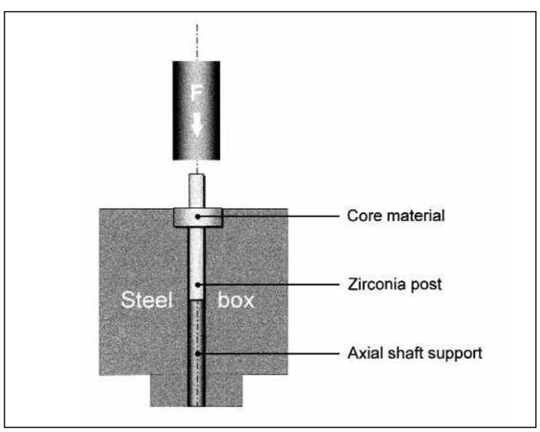

Figure 4. *Testing device used for measurement of core retention.*

The results of the light microscope defect analyses prior to testing procedure are reported in Table 2. Group 3 showed the highest number and diversity of defects. Two typical examples of severe defects occurring in specimens of Group 3 and 4 are shown in Figure 5a and Figure 5b. In Groups 1 and 5, no defects were detected.

The mean separation loads recorded ranged from 194.48 (Group 4) to 765.48 Newtons (Group 3) and are shown in Figure 6. The exceptionally high values of Group 3 were accompanied by an extremely high standard deviation. Statistically, no significant differences (p>0.05) were found among Groups 1, 2, 4 and 5.

Fracture analyses by SEM evaluation showed characteristic failure modes dependent on the specimen groups. The major part of the fracture lines followed the pattern of preexisting defects (Figure 7, 8 and 9).

DISCUSSION

The results of this study emphasize the importance of a detailed defect analysis prior to the test procedures. If separation loads were the only factor considered in the evaluation of the retention, Group 3 would be evaluated as a suitable combination. In Group 3, an experimental heat-pressed core ceramic (EX) was pressed directly onto the post. However, defect analysis shown for this group exhibited the highest number and diversity of severe defects (Table 2). Also, with a separate ring-shaped core made of EX, which was adhesively bonded to the post (Group 4), a high number of severe defects including chipping occurred (Table 2). The circular and radial cracks detected in Group 3 and 4 are explained by the excessive differences of the CTE

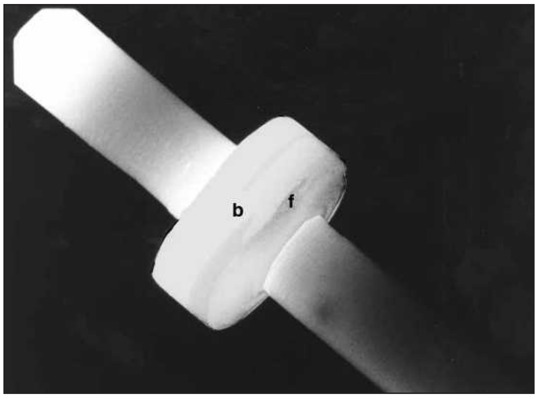

Figure 5a. *Example of the arrangement of circular cracks (b), and a chipped piece (f) observed in the core material EX (Group 4).*

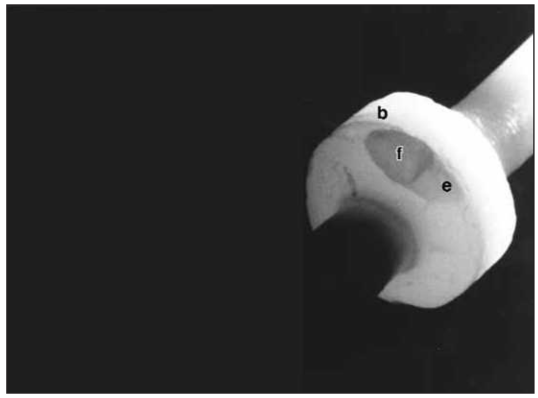

Figure 5b. *Example of the arrangement of circular cracks (b), a separated piece (e), and a chipped piece (f) observed in the core material EX (Group 4).*

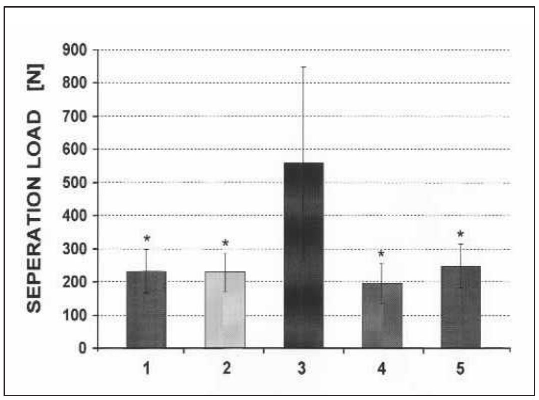

Figure 6. *Separation loads applied to the specimens of the different groups (Mean and standard deviation). Columns marked with an asterisk are not signficantly different (*: p>0.05).*

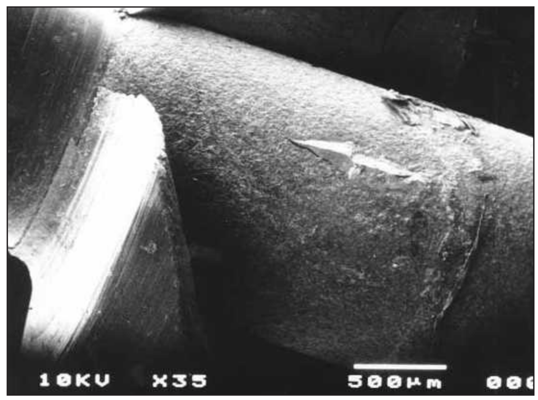

Figure 7. *Scanning electron photomicrograph after separation of a composite core from a tribochemically silicoated zirconia post (Group 2).*

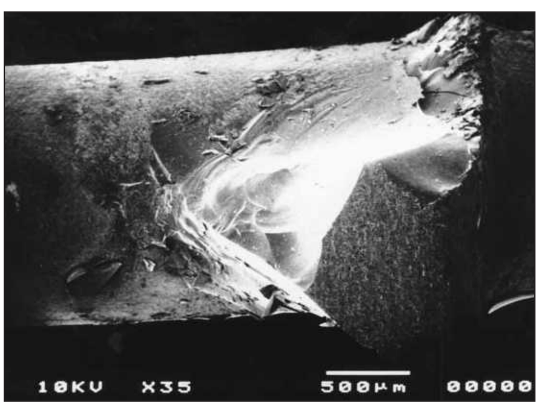

Figure 8. *Scanning electron photomicrograph after separation of a core made of heat pressed experimental glass-ceramic from a alumina abraded zirconia post (Group 3). Given the severe defects prior to testing procedure (Figure 5a and 5b) almost all core components were separated from the post.*

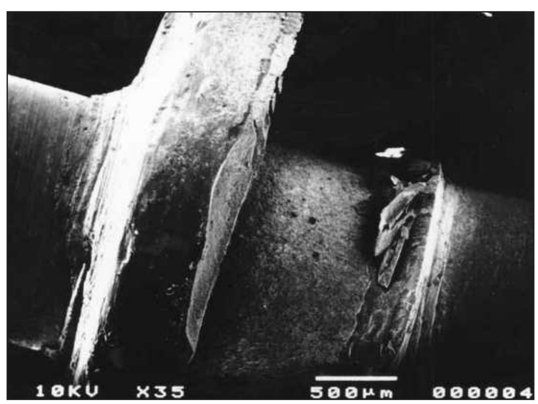

Figure 9. *Scanning electron photomicrograph after separation of a core made of a corresponding heat pressed glass-ceramic from a alumina abraded zirconia post (Group 5).*

(µm/m·°C) 10.7 (value reported by the manufacturer) to the zirconia ceramic. For partially stabilized zirconia, a CTE of 9.7 * 10^{-6} K^{-1} (100-500°C) was determined (Schweiger & others, 1999). Since the composition of the two post types tested is nearly the same (information given by the manufacturers), the findings are transferable. Due to the higher CTE of the experimental ceramic core material EX, tensile forces are generated by increased shrinkage onto the zirconia post during the cooling process. This mechanism explains the high loads measured for complete separation of the specimens in Group 3. The high sensitivity to tensile forces of ceramic internal microstructure ceramics accelerates the growth of microcracks (Scherrer & others, 1999). This is confirmed by the high number of radial and circular cracks in EX. Those cracks may be propagated by *in vivo* masticatory stresses resulting in complete failure, similar to defects detected as partial chipping in core material EX. Apparently, the thickness of the cement layer was not fully capable of compensating for the stresses caused by the misfit of CTEs between the core and post ceramic. Therefore, the use of the experimental high-strength glass ceramic as core material for zirconia root posts (Group 3 and 4) is not suitable.

Contrasting this are Groups 1 and 5, where a specially designed pressable core ceramic was employed and no defects in the core material were detected. The CTE of this glass-ceramic (Schweiger & others, 1999), 9.4 $*10^{-6}$ K^{-1} (100-500°C) seems to be ideally adjusted to the CTE of the zirconia post. A smaller contraction of the core ceramic compared to the post material during cooling procedure results in residual compressive stresses. The presence of microcracks and the growth of microflaws is reduced, requiring higher stress application to generate tensile failure.

The values for the separation load of Groups 1 and 5 were slightly higher compared to those determined by other investigators (Kakehashi & others, 1998). This discrepancy can be explained by the use of a greater post diameter: 1.4 mm (Kakehashi & others, 1998) compared to approximately 1.7 mm in this study.

The incremental application of the highly viscous composite TEC as a direct core material in Group 2 resulted in a high number of air inclusions. As this method represents the clinical procedure, the same occurrence of voids can be expected clinically (Gjerdet NR & Hegdahl T, 1978; Mentink & others, 1995). *In vitro* studies demonstrated that the presence of porosity reduced the amount and rate of shrinkage stress development (Alster & others, 1992). On the other hand, porosity decreases the strength of the core and an acceleration of hydrolytic degradation can occur (Prati & others, 1991).

Commonly used zirconia ceramics obtain their superior mechanical properties by the stabilization of a tetragonal crystalline structure, which is metastable at room temperature. This crystalline formation provides an effective mechanism acting against flaw propagation but can be altered to less effective structure under unfavorable temperature conditions. Zirconia ceramic has a thermal conductivity only one-tenth that of alumina ceramic. In this context, heat generating surface treatments can cause localized overheating by very slow heat transmission. Also, air abrasion procedures can induce extremely high surface temperatures due to the transformation of kinetic energy at the local impact area of the grain (Musil & Tiller, 1989). This is an important aspect of this surface conditioning as it generates a durable adhesive bond to zirconia surfaces (Edelhoff & others, 2000a; Göbel & others, 1998; Kern & Wegner, 1998). However, using air abrasion showed a significant increase in strength of the zirconia posts when used without any pretreatment of the surface (Kosmac & others, 1999). This finding is explained by residual compression stresses induced in the surface by the embedded silica and alumina particles (Fischer, Edelhoff & Marx, 1998).

An additional potential weakening of the zirconia posts could occur with the use of the indirect technique during the burn-out process and direct application of the heat-pressed ceramic as the core. An *in vitro* investigation demonstrated that a temperature pattern simulating the heat pressing procedure for the adaptation of the core material did not significantly affect the strength of the zirconia post (Fischer & others, 1998).

The testing device used in this study allowed for the fabrication of specimens in a design that is similar to the clinical application. However, there are limitations to the clinical relevance of the presented results: due to the test specimen's geometry, a major part of the core retention is created by micro- and macroretentions. If only the adhesive bond strength was of major interest, a three-point-bending test (Edelhoff & others, 2000a) or a tensile test should be conducted (Kern, Simon & Strub, 1998). In addition, the test force application was axial, where anterior masticatory forces are almost never along the axis of the post.

The material combinations and bonding procedures tested in this study have been used for several years by one of the authors in a clinical study. The first few years' clinical results are promising (Edelhoff, Spiekermann & Yildirim, 2000b).

CONCLUSIONS

Within the limits of the experimental model presented, it can be concluded that:

1. Only the combination of alumina abrasion and heat-pressed zirconia-containing glass ceramic as core material showed no defects, a durable retention to both types of zirconia posts and is suitable as an indirect technique.
2. The combination of tribochemical silicoating and fine-particle hybrid composite material can be recommended as a direct technique.
3. An excessive discrepancy in the coefficient of thermal expansion match between the core material and the zirconia post generated a high number and diversity of severe defects in the core, independent of the method of core adaptation and can therefore not be recommended.

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Surface Texture of Resin-Modified Glass Ionomer Cements: Effects of Finishing/Polishing Time

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Clinical Relevance

Delayed finishing/polishing of resin-modified glass ionomer cements is recommended as it generally produces smoother surfaces and reduces the effects of finishing/polishing systems on surface roughness.

SUMMARY

This study compared the surface texture of resin-modified glass ionomer cements after immediate and delayed finishing with different finishing/polishing systems. Class V preparations were made on the buccal and lingual/palatal surfaces of 64 freshly extracted teeth. The cavities on each tooth were restored with Fuji II LC (GC) and Photac-Fil Quick (3M-ESPE) according to manufacturers' instructions. Immediately after light-polymerization, gross finishing was done with 8-fluted tungsten carbide burs. The teeth were then randomly divided into four groups of 16 teeth. Half of the teeth in each group were finished immediately, while the remaining half were finished after one-week storage in distilled water at 37ºC. The following finishing/polishing systems were employed: (a) Robot Carbides; (b) Super-Snap system; (c) OneGloss and (d) CompoSite Polishers. The mean surface roughness (µm; n=8) in vertical (RaV) and horizontal (RaH) axis was measured using a profilometer. Data was subjected to ANOVA/Scheffe's tests and Independent Samples t-test at significance level 0.05. Ra values were generally lower in both vertical and horizontal axis with delayed finishing/polishing. Although significant differences in RaV and RaH values were observed among several systems with immediate finishing/polishing, only one (Fuji II LC: RaH - Super-Snap < Robot Carbides) was observed with delayed finishing.

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INTRODUCTION

Resin-modified glass ionomer cements were introduced to help overcome the problems of moisture sensitivity and low early mechanical strength associated with conventional glass ionomer cements, while maintaining their clinical advantages of fluoride release and chemical bonding to tooth (Wilson, 1990; Sidhu & Watson, 1995). In resin-modified glass ionomer cements, a second, light-initiated curing process supplements the fundamental acid-base curing reaction. In their simplest form, they are glass ionomer cements with a small quantity of resin components such as hydroxyethyl methacrylate (HEMA) or Bisphenol A-glycidyl methacrylate (BISGMA). More complex materials have been developed by modifying the polyacid with side chains that can polymerize by light-curing mechanisms. According to most manufacturers, the finishing/polishing of resin-modified glass ionomer cements can be conducted immediately after light curing. It is important to note, however, that light polymerization only sets the resinous components, and the acid-base curing reaction that serves to harden and strength the formed polymer matrix is relatively immature after light curing. The acid-base reaction may actually be retarded in resin-modified glass ionomer cements due to the replacement of water, which serves as the reaction medium, with water/resin mixtures (Yap, 1996; Wan, Yap & Hastings, 1999).

Several investigators have reported on the surface roughness of resin-modified cements after finishing/polishing (Wilder & others, 2000; Hoelscher & others, 1998; Hondrum & Fernandez, 1997: Yap, Lye & Sau, 1997; Tate & Powers, 1996: St Germain & Meiers, 1996). These studies have not provided a consensus regarding the relative effectiveness of the various finishing/polishing techniques when used in the clinical situation and the optimal finishing/polishing time. The latter is important, as immediate finishing/polishing may enhance preferential removal of the immature polysalt matrix and increase surface roughness of resin-modified glass ionomer restorations (Yap, Sau & Lye, 1998). Residual surface roughness of restorations encourages plaque accumulation, which may lead to gingival inflammation, secondary caries and superficial staining. This study compared the effects of immediate and delayed finishing/polishing on the surface texture of resin-modified glass ionomer cements based on a tooth model. Surface roughness in the vertical and horizontal axis after finishing/polishing with the different systems was also compared.

METHODS AND MATERIALS

Table 1 shows the resin-modified glass ionomer cements investigated and their technical profiles. Sixty-four freshly extracted, non-carious premolars were selected for this study. The teeth were disinfected with 2% formaline-saline, cleaned and stored in distilled water at 4°C until use. The apical third of the root(s) of each tooth were embedded in square acrylic blocks approximately 10 mm in length, breadth and height. These acrylic blocks were used to fasten restored tooth specimens to the precision vice of the profiling instrument during roughness measurements. Wedge-shaped Class V preparations (approximately 4 mm wide (mesio-distally), 3 mm long (occluso-gingivally) and 2 mm (deep) were made on the buccal and lingual/palatal surfaces of each tooth. The cavities on each tooth were restored with capsulated Fuji II LC (GC) and Photac-Fil Quick (3M-ESPE, St Paul, MN 55144, USA). Shade A2 was used for both materials to standardize the depth of cure. Cavities to be restored with Fuji II LC were first treated with Cavity Conditioner (GC) for 10 seconds, while cavities to be restored with Photac-Fil Quick were treated with Ketac Conditioner (3M-ESPE) for 10 seconds. The cavities were then washed for 30 seconds and gently air dried. The resin-modified glass ionomer cements were mixed according to manufacturers' instructions and injected into the cavities. Transparent preformed cervical matrixes (Hawe-Neos Dental, Bioggio, Switzerland) were placed over the filled cavities and pressure was applied to extrude excess material, which was subsequently removed. The cements were then light polymerized for 20 seconds using a curing light (Spectrum; Dentsply Inc, Milford, DE 19963, USA) with an output intensity ≥ 420 mW/cm^2, as assessed with a curing radiometer (Cure Rite, EFOS Inc, Ontario, Canada).

Immediately after light-polymerization, the cervical matrixes were removed and gross finishing was done with 8-flute tungsten carbide burs (Robot Carbide SH134; Shofu, Kyoto, Japan). Gross finishing was done in one direction under water spray using a high-speed handpiece at 300,000 rpm. The burs were replaced after gross finishing of every eight restorations. The restored teeth were then randomly divided into four groups of 16 teeth. Half of the teeth in each group were finished/polished immediately after light curing, while the remaining half were finished/polished after one week. The storage medium during the hiatus period was distilled water at 37ºC. A layer of unfilled resin (Fuji Coat LC [GC]/Ketac Glaze [3M-ESPE]) was placed over the restorations (Fuji II LC/Photac-Fil, respectively) and light cured for 10 seconds prior to storage in water. The finishing/polishing systems employed included carbide burs (Robot Carbides), graded abrasive disks (Super-Snap), one-step (OneGloss) and two-step (CompoSite Polishers) rubber abrasives. With the exception of Super-Snap, the shanks of all instruments were aligned to the long axis of the tooth during finishing/polishing procedures. Details of the finishing/polishing sequences are reflected in Table 2. After finishing/polishing, the specimens were washed and the mean surface roughness (µm) in vertical (RaV) (along the long-axis of the tooth) and horizontal (RaH) axis (mesio-distally) was measured using a profilometer (Surftest SV-400; Mitutoyo, Kanagawa, Japan). Readings were taken at the center of each restoration. Four sampling lengths of 0.25 mm were used giving a total evaluation of 1 mm. The profilometer was accurate to 0.01 mm and measurements were 90% reproducible based on 10 readings of a precision reference specimen (178-602, Mitutoyo, Kanagawa, Japan) of known surface roughness. All statistical analysis carried at significance level 0.05. Multiple ANOVA was used to determine significant interactions among the various independent variables.

Table 1: *Technical Profiles of the Resin-Modified Glass Ionomer Cements Investigated*

Material	Manufacturer	Components	Mean Particle Size (µm)	Lot #
Fuji II LC	GC Corporation, Tokyo, Japan	*Powder:* Alumino silicate glass, pigments *Liquid:* Polyacrylic acid, distilled water, HEMA (17%), dimethacrylate monomer, camphoroquinone	4.5	9912202
Photac-Fil Quick	3M-ESPE Dental, Seefeld, Germany	*Powder:* Calcium aluminium fluorosilicate glass, copolymers of acrylic and maleic acids, tartaric acid, activator, pigments *Liquid:* HEMA (40%), difunctional monomer, water, camphoroquinone	7.0	0065231

Table 2: *Finishing/Polishing Systems and Sequences*

Product	Usage	Handpiece Speed	Manufacturer
Robot Carbide			Shofu Inc,
SH134F	Wet, 12 strokes	300,000 rpm	Kyoto, Japan
SH134UF	Wet, 12 strokes	300,000 rpm	
Super-Snap			Shofu Inc,
Coarse	Dry, 6 strokes	12,000 rpm	Kyoto, Japan
Medium	Dry, 6 strokes	12,000 rpm	
Fine	Dry, 6 strokes	12,000 rpm	
Extra fine	Dry, 6 strokes	12,000 rpm	
OneGloss	Wet, 12 heavy strokes	10,000 rpm	Shofu Inc,
	Wet, 12 light strokes	10,000 rpm	Kyoto, Japan
CompoSite Polishers			
CompoSite	Wet, 12 strokes	12,000 rpm	Shofu Inc,
CompoSite Fine	Dry, 12 strokes	12,000 rpm	Kyoto, Japan

One-way ANOVA and Scheffe's post-hoc tests were used to compare the surface roughness obtained with the different finishing/ polishing systems, while Independent Samples *t*-tests were employed to evaluate differences between time of finishing/polishing and materials.

RESULTS

The mean surface roughness obtained with immediate and delayed finishing/polishing are shown in Table 3. Tables 4 through 6 show the results of statistical analysis.

With immediate finishing, mean RaV ranged from 0.59 - 1.31 and 0.83 – 1.52 µm. while mean RaH ranged from 0.80 – 1.43 and 0.85 – 1.58 µm for Fuji II LC and Photac-Fil, respectively. With delayed finishing/polishing, mean RaV ranged from 0.65 – 1.10 and 0.47 – 1.44 µm, while mean RaH ranged from 0.72 – 1.44 and 0.81 – 1.45 µm for Fuji II LC and Photac-Fil, respectively. MANOVA revealed significant interactions among materials, finishing/polishing systems, measurement axis and time when finishing/polishing is conducted. Although significant differences in RaV and RaH values were observed among several systems with immediate finishing/polishing (Table 4), only one was observed with delayed finishing. For Fuji II LC, delayed finishing with Robot Carbides resulted in significantly higher RaH values compared to Super-Snap. RaV and RaH values were generally lower with delayed finishing/polishing. Significant differences in Ra values were observed for a few finishing/polishing system-material combinations (Table 5). For Photac-Fil, delayed finishing with Super-Snap and OneGloss resulted in significantly lower RaV values compared to immediate finishing. Delayed finishing/polishing of Fuji II LC with CompoSite also resulted in lower RaV values compared to immediate finishing. In the horizontal axis, significantly lower Ra values were obtained for Photac-Fil when finishing/polishing with OneGloss was delayed. With immediate finishing/polishing, significant differences in surface roughness were observed between Fuji II LC and Photac-Fil for vertical measurements after treatment with Super-Snap and horizontal measurements after treatment with CompoSite (Table 6). No significant difference in Ra values in both vertical and horizontal axis was observed between materials when finishing/polishing was delayed.

DISCUSSION

Although restoratives that are cured against a matrix are not devoid of surface flaws, they impart the smoothest surface possible (Yap & others, 1997). Despite careful placement of matrixes, the removal of excess material and contouring of restorations is usual-

Table 3: *Mean Ra Values (n=8) and Standard Deviations in Parenthesis*

Product	Materials	RaV (µm)		RaH (µm)	
		Immediate	Delayed	Immediate	Delayed
Robot Carbide	Fuji II LC	0.93 (0.30)	0.80 (0.49)	1.43 (0.26)	1.44 (0.76)
	Photac-Fil	1.29 (0.37)	1.44 (0.21)	1.58 (0.33)	1.45 (0.80)
Super-Snap	Fuji II LC	0.59 (0.16)	0.65 (0.36)	0.80 (0.29)	0.72 (0.18)
	Photac-Fil	0.92 (0.22)	0.47 (0.26)	0.85 (0.17)	0.81 (0.30)
OneGloss	Fuji II LC	1.31 (0.19)	1.10 (0.32)	1.23 (0.15)	1.09 (0.33)
	Photac-Fil	1.52 (0.32)	1.03 (0.43)	1.41 (0.26)	1.04 (0.36)
CompoSite	Fuji II LC	1.00 (0.32)	0.70 (0.23)	0.80 (0.22)	0.90 (0.37)
Polishers	Photac-Fil	0.83 (0.36)	0.61 (0.21)	1.13 (0.28)	1.06 (0.40)

Table 4: *Comparison of RaV and RaH Between Finishing/Polishing Systems*

Ra	Materials	Differences
		Immediate Finishing/Polishing
Vertical (RaV)	Fuji II LC	Robot Carbide, Super-Snap < OneGloss Super-Snap < CompoSite
	Photac-Fil	Super-Snap, CompoSite < OneGloss
Horizontal (RaH)	Fuji II LC	Super-Snap, CompoSite < Robot Carbide, OneGloss
	Photac-Fil	Super-Snap < Robot Carbide, OneGloss CompoSite < Robot Carbide
		Delayed Finishing/Polishing
Vertical (RaV)	Fuji II LC	NS
	Photac-Fil	NS
Horizontal (RaH)	Fuji II LC	Super-Snap < Robot Carbide
	Photac-Fil	NS

< indicates statistically significant difference and NS indicates no statistical significance. Results of one-way ANOVA/Scheffe's test (p<0.05).

ly necessary clinically. This requires some degree of finishing and polishing that violates the smoothness obtained with a matrix (Lui & Low, 1982). Finishing refers to the gross contouring or reducing of restorations to the desired anatomy. Polishing refers to the reduction of roughness and scratches caused by the finishing instruments. The demarcation between finishing and polishing is, however, seldom clear and hence use of the term finishing/polishing in this paper. A critical threshold surface roughness for bacteria adhesion has been suggested by *in vivo* studies (Bollen, Lambrechts & Quirynen, 1997). No further reduction in bacterial accumulation is expected below this threshold surface roughness of 0.2 µm. Any increase in surface roughness above this threshold roughness results in simultaneous increase in plaque accumulation and increases the risk for caries and periodontal inflammation (Bollen & others, 1997). As all finished/polished surfaces had Ra values greater than 0.2 µm, any reduction in surface roughness resulting from delayed finishing/polishing can be deemed clinically relevant.

For conventional glass ionomer cements, finishing/polishing is best delayed for at least 24 hours. Pearson (1991) found that delaying finishing/polishing for 24 hours resulted in marked reduction in surface irregularities regardless of the finishing/polishing system used. Early finishing/polishing (10 minutes after placement) resulted in smearing, flaking and crack faults developing on the surface. Brackett & Johnston (1989), however, found that conventional glass ionomers attained 29% of their 24-hour hardness after 15 minutes and no difference in surface characteristics, appearance or roughness between specimens that were finished/polished after 15 minutes and 24 hours. Their results were corroborated by a five-year clinical study that found no significant difference between cervical glass ionomer restorations that were finished more than 15 minutes and 24 hours after placement (Matis & others, 1991). The discrepancy may be attributed to the five-minute time difference that has implications on the state of chemical maturity at the point of instrumentation. Based on the aforementioned, the minimal waiting time prior to finishing/polishing of resin-modified glass ionomer cements should be at least 15 minutes assuming that resin-modification does not affect the acid-base reaction. The acid-base complexation reaction of resin-modified glass ionomer cements was, however, found to be complete only after 168 hours (one week) as compared to 24 hours for conventional glass ionomer cements (Wan & others, 1999). A one-week storage period after placement was thus selected for delayed finishing/polishing. In addition, this hiatus period was clinically relevant and practical. A layer of light-cured unfilled resin was applied according to the manufacturer's recommendation. It was subsequently removed during fine finishing and polishing procedures after the one-week storage period.

The effects of finishing/polishing systems on surface roughness of resin-modified glass ionomer cements had been described in detail in our previous paper (Yap & others, 2002). Although significant differences in Ra values were observed in the vertical and horizontal axis between several systems with immediate finishing/polishing, only one significant difference was observed with delayed finishing. The effects of finishing/polishing systems on surface roughness of resin-modified glass ionomer cements were therefore curtailed by delayed instrumentation. This could be attributed to increased maturity of the polysalt matrix and hence hardness after one week. During finishing/polishing, the softer polysalt and resin matrixes between the harder unreacted glass particles are preferentially abraded. As the resin component only constitutes 4.5 to 6% of the final set restoration (Sidhu & Watson, 1995), the hardness of the supporting matrix is determined primarily by the state of maturity of the polysalt network. A larger disparity in hardness between the phases, as in the case of immediate finishing/polishing, might result in greater removal of the polysalt matrix during instrumentation. Eventually, the unreacted glass particles are left unsupported and can be easily exfoliated. The unprotected matrix wears away with further finishing/polishing and the process continues. With delayed finishing/polishing, the polysalt matrix attains optimal hardness and is less prone to the differential effects of instrumentation. This accounts for the general lack of statistical significance among different finishing/polishing systems. For Fuji II LC, delayed finishing with Robot Carbides resulted in significantly higher RaH values compared to Super-Snap. This finding is consistent with that of St Germain & Meiers (1996) and may be attributed to the orientation of the flutes on the carbide burs.

Table 5: *Comparison of RaV and RaH Between Immediate and Delayed Finishing/Polishing*

Ra	Products	Materials	Differences
Vertical (RaV)	**Robot Carbide**	**Fuji II LC**	NS
		Photac-Fil	NS
	Super-Snap	**Fuji II LC**	NS
		Photac-Fil	Delayed < Immediate
	OneGloss	**Fuji II LC**	NS
		Photac-Fil	Delayed < Immediate
	CompoSite Polishers	**Fuji II LC**	Delayed < Immediate
		Photac-Fil	NS
Horizontal (RaH)	**Robot Carbide**	**Fuji II LC**	NS
		Photac-Fil	NS
	Super-Snap	**Fuji II LC**	NS
		Photac-Fil	NS
	OneGloss	**Fuji II LC**	NS
		Photac-Fil	Delayed < Immediate
	CompoSite Polishers	**Fuji II LC**	NS
		Photac-Fil	NS

< indicates statistically significant difference and NS indicates no statistical significance. Results of Independent Samples t-test *(p<0.05).*

Table 6: *Comparison of RaV and RaH Between Materials*

Ra	Products	Finishing/Polishing Time	Differences
Vertical (RaV)	**Robot Carbide**	**Immediate**	NS
		Delayed	NS
	Super Snap	**Immediate**	Fuji II LC < Photac-Fil
		Delayed	NS
	OneGloss	**Immediate**	NS
		Delayed	NS
	CompoSite Polishers	**Immediate**	NS
		Delayed	NS
Horizontal (RaH)	**Robot Carbide**	**Immediate**	NS
		Delayed	NS
	Super Snap	**Immediate**	NS
		Delayed	NS
	OneGloss	**Immediate**	NS
		Delayed	NS
	CompoSite Polishers	**Immediate**	Fuji II LC < Photac-Fil
		Delayed	NS

< indicates statistically significant difference and NS indicates no statistical significance. Results of Independent Samples t-test *(p<0.05).*

Ra values were generally lower in both vertical and horizontal axis with delayed finishing/polishing. Significant differences in Ra values were, however, observed only for four finishing/polishing system-material combinations. The benefits of delayed finishing/polishing appeared to be more substantial for Photac-Fil compared to Fuji II LC. The larger mean particle size of Photac-Fil results in larger inter-particle spacing, which offers less protection to the softer polysalt/resin matrix. The aforementioned might explain the significantly better results observed with delayed finishing/polishing of Photac-Fil. With immediate finishing/polishing, significant differences in surface roughness were observed between Fuji II LC and Photac-Fil for vertical measurements after treatment with Super-Snap and horizontal measurements after treatment with CompoSite. These findings were attributed to the discrepancy in mean particle size and lower effectiveness of the other finishing/polishing systems (Yap & others, 2002). With delayed finishing/polishing, no significant difference in RaV and RaH values was observed between Fuji II LC and Photac-Fil for all finishing/polishing techniques. The higher abrasion resistance of the polysalt matrix when finishing/polishing procedures are delayed can also account for this. In addition to surface roughness, immediate finishing/polishing could compromise the marginal seal of resin-modified glass ionomer cements to tooth. Although immediate finishing/polishing did not affect marginal seal to dentin, it increased microleakage at enamel margins (Lim, Neo & Yap, 1999). Delayed finishing/polishing may also increase the surface hardness of resin-modified glass ionomer cements (Yap & others, 1998). The latter could have implications on the clinical longevity of restorations. This phenomenon was attributed to moisture contamination and dehydration arising from finishing/polishing procedures during the initial acid-base setting reaction (Mount & Makinson, 1982). In view of the aforementioned and current studies, the delayed finishing/polishing of resin-modified glass-ionomer cements is advocated in spite of manufacturers' suggestions of immediate instrumentation.

CONCLUSIONS

Under the conditions of this *in vitro* study:

1. The effects of finishing/polishing systems on the surface roughness of resin-modified glass ionomer cements were time-dependent.

2. When finishing/polishing was delayed for one week, no significant difference in roughness was observed between treatment with graded abrasive disk (Super-Snap), one (OneGloss) and two-step (CompoSite Polishers) rubber abrasive systems.

3. Surface roughness in the horizontal and vertical axis was generally lower with delayed finishing/polishing.

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Changes in Flexural Properties of Composite Restoratives After Aging in Water

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Clinical Relevance

Depending on their application, the clinical durability of composite restorations may be compromised due to changes in flexural properties with aging.

SUMMARY

This study evaluated the changes in flexural properties of microfill (Filtek A110 [AO]), minifill (Filtek Z100 [ZO] and Z250 [ZT]), poly-acid modified (F2000 [FT]), and flowable (Filtek Flowable [FF]) composites after aging in water. The flexural strength and modulus of the composites were determined after one week and one month of aging in water at 37ºC. Samples were prepared and tested according to ISO specifications. Data was analyzed using ANOVA/Scheffe's test and independent samples *t*-test at significance level 0.05. Mean flexural strength (n=7) ranged from 66.61 to 147.21 and 68.74 to 142.69 MPa at one week and one month, respectively. Mean flexural modulus (n=7) at one week and one month ranged from 3.45 to 11.30 and 4.76 to 13.02 GPa, respectively. ZO and ZT were significantly stronger than AO, FT and FF and FF was significantly stronger than AO & FT at both time periods. At one week and one month, AO and FF were significantly more flexible than the ZO, ZT and FT. In addition, ZO and FT were significantly stiffer than ZT. With the exception of AO, a significant increase in flexural modulus was observed with all composites. Although flexural strength of FT and FF was significantly increased with aging in water, the flexural strength of ZT was significantly decreased.

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INTRODUCTION

Composites can be defined as three-dimensional combinations of at least two chemically different materials with a distinct interface (Phillips, 1981). Dental composites are essentially comprised of a resin matrix (organic phase), inorganic filler particles (dispersed phase), filler-matrix coupling agent (interface) and minor additions including polymerization initiators, stabilizer and coloring pigments. They can be classified by their filler particles into midifills (average size = 1-5 µm), minifills (average size = 0.6-1.0 µm) and microfills (average size = 0.04 µm) (Ferracane, 1995). Composites are routinely used in Class III, IV and V restorations, and with increasing frequency in Class I and II restorations. Clinically, composite restorations can be subjected to considerable flexural stresses (Anusavice, 1996). The required flexural properties are highly dependent on the clinical applications. In Class I, II, III and IV restorations, where stresses are significant, high flexural strength and modulus are desired. Materials with low modulus or stiffness will deform more under masticatory stresses resulting in catastrophic failures and destruction of the marginal seal between the composites and tooth substance (McCabe, 1994; Lambrechts, Braem & Vanherle, 1987). In Class V restorations, composites with lower modulus are desired as they are capable of flexing during tooth function. The latter may reduce stresses along the bonding agent interface and the likelihood of debond (Bayne, Heymann & Swift, 1994).

Over the past decade, there has been a rapid increase in the number and type of composite products available. Two of the more significant innovations are polyacid-modified and flowable composites. Polyacid-modified composites are those that contain either or both essential components of a glass ionomer (that is, acid polymer and basic glass). The components, however, do not react as part of the setting process (McLean, Nicholson & Wilson, 1994). Polyacid-modified composites are usually indicated for non-stress bearing areas (Class V and small Class III restorations), although some manufacturers have claimed that their products are formulated for both anterior and posterior usage. The major advantage of polyacid-modified composites over other composites is dependable fluoride release (Yap, Khor & Foo, 1999). Flowable composites are basically syringeable low viscosity composites that were created by reducing filler content (Bayne & others, 1998). In addition to the restoration of Class V cavities, flowable composites can also be used to seal teeth after air abrasion, small repair of teeth/composites/porcelain, pediatric restorations and small Class III and lining Class II composite restorations.

Although the flexural properties of composite restoratives have been widely reported (Iazzetti, Burgess & Gardiner, 2001; Cobb & others, 2000; Manhart & others, 2000; Yap & others, 2000a; Gladys & others, 1997), little is known about the effects of aging on the flexural properties of newer composites including polyacid-modified and flowable materials (Ferracane, Hopkin & Condon, 1995). This study evaluated the changes in flexural strength and modulus of microfill, minifill, polyacid-modified and flowable composites after aging in water. The flexural properties of the different composites were also compared.

METHODS AND MATERIALS

Table 1 shows the materials evaluated and their technical profiles. They included a microfill composite (A110), two minifill composites (Z100 and Z250), a polyacid-modified composite (F2000) and a flowable composite (Filtek Flow). These materials represent the

Table 1: *Materials Evaluated and Their Technical Profiles*

Material	Manufacturer	Cure Time	Resin	Filler	Filler Size (µm)	Filler Content % by Volume
Filtek A110 (Lot #20001128)	3M Dental Products St Paul, MN 55144	40 seconds	BISGMA TEGDMA	Colloidal Silica	0.01 -0.09	40
Z100 (Lot #20010404)	3M Dental Products St Paul, MN 55144	40 seconds	BISGMA TEGDMA	Zirconia/ Silica	0.01 -3.5	66
Filtek Z250 (Lot #20010402)	3M Dental Products St Paul, MN 55144	20 seconds	BISGMA UDMA BisEMA	Zirconia/ Silica	0.01 -3.5	60
F2000 (Lot #20010122)	3M Dental Products St Paul, MN 55144	40 seconds	CMDA GDMA	Fluro-alumino-silicate glass, silica	3-10	67
Filtek Flow (Lot #20010410)	3M Dental Products St Paul, MN 55144	20 seconds	BISGMA TEGDMA	Zirconia/ Silica	0.01 -6	47

BISEMA = Ethoxylated bisphenol-A-glycidyl methacrylate
BISGMA = Bisphenol-A-glycidyl methacrylate
CDMA = Dimethacrylate functional oligomer derived from critic acid
GDMA = Glyceryl methacrylate
TEDGMA = Triethylene glycol dimethacrylate
UDMA = Urethane dimethacrylate

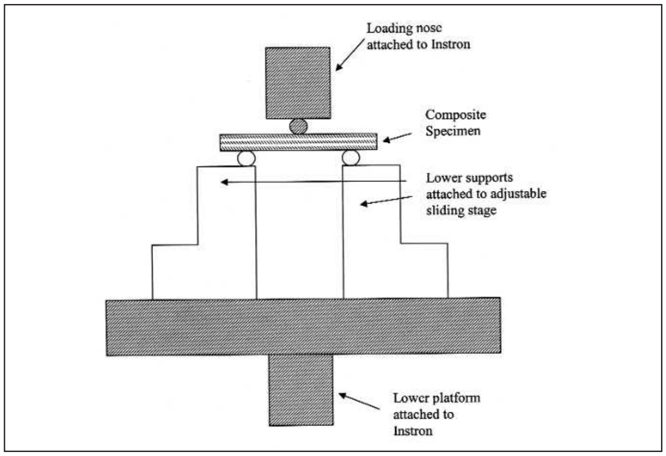

Figure 1. *Diagrammatic representation of the flexural testing apparatus.*

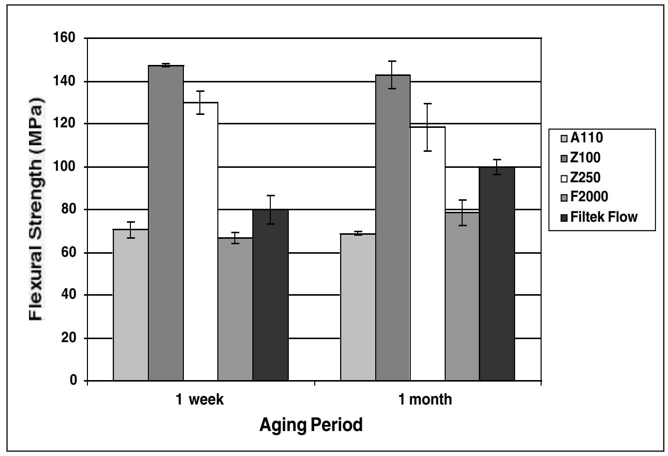

Figure 2. *Mean flexural strength of the composites.*

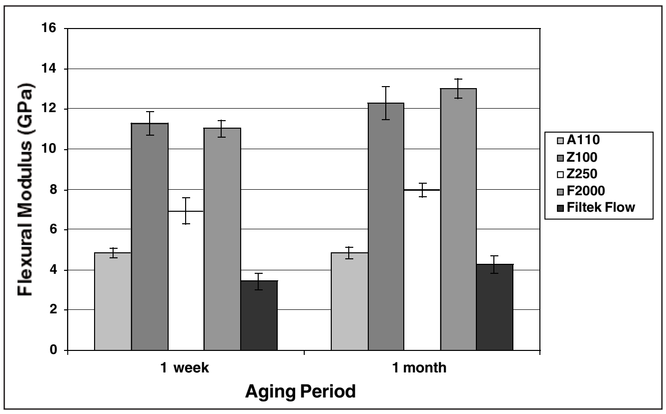

Figure 3. *Mean flexural modulus of the composites.*

spectrum of commercial composite materials that are currently available. All materials were from the same manufacturer and of the A2 shade. Flexural test specimens (25 mm length x 2 mm breath x 2 mm height) of the various restoratives were fabricated according ISO 4049 specifications in customized stainless steel molds. The restoratives were placed into the mold, which was positioned on top of a glass slide. A second glass slide was then placed on top of the mold and gentle pressure was applied to extrude excess material. The top and bottom surfaces were then light polymerized in three overlapping irradiations of 20 to 40 seconds each (depending of the manufacturer's recommendations), using a curing light (Spectrum; Dentsply Caulk, Milford, DE 19963, USA) with an exit window of 13 mm and an output intensity ≥ 420 mW/cm^2 as assessed with a curing radiometer (Cure Rite, EFOS Inc, Ontario, Canada). The center sections of the specimens were cured first. After light polymerization, the assembly was placed in a water bath for 15 minutes. The flash was then removed and the test specimens separated from their molds and stored in distilled water at 37 ± 1°C. Fourteen specimens of each composite were fabricated. Half of the specimens were tested after one week and the remaining half were tested after one month of aging in water.

At the end of each aging period, the flexural properties of the composites were assessed. The specimens were first blotted dry, sized with sandpaper and measured using a digital vernier caliper (Mitutoyo Corporation, Tokyo, Japan). Measurements were taken in two locations for length, breath and height, and the average of the two values was taken to calculate the flexural strength. The specimens were subsequently transferred to a flexural strength testing apparatus (Figure 1) mounted on an Instron Universal testing machine (Instron model 4502, Canton, MA 02021, USA). The water surrounding the apparatus and specimens was maintained at 37 ± 1°C and the specimens were allowed to stabilize for 10 minutes prior to testing. A crosshead speed of 0.75 mm/minute was used and the maximum loads exerted on the specimens prior to fracture were recorded. Flexural strength, σ, in megapascals (MPa) was calculated using the following equation:

$$\sigma = \frac{3FL}{2BH^2}$$

Where

F is the maximum load, in newtons, exerted on the specimens;

L is the distance, in millimeters, between the supports (20 mm);

B is the width, in millimeters, of the specimen measured immediately prior to testing;

H is the height, in millimeters, of the specimens measure immediately prior to testing.

Flexural modulus, E, in megapascals (MPa) was calculated using the following equation:

$$E = \left(\frac{F_1}{D}\right)\left(\frac{L^3}{4BH^3}\right)$$

Table 2: *Mean Flexural Strength and Modulus of the Composite Materials After the Two Aging Periods*

Materials	Flexural Strength (MPa)		Flexural Modulus (GPa)	
	7 days	30 days	7 days	30 days
A110	70.61 (3.71)	68.74 (0.78)	4.85 (0.26)	4.86 (0.29)
Z100	147.21 (0.70)	142.69 (6.56)	11.30 (0.58)	12.29 (0.81)
Z250	130.07 (5.43)	118.37 (11.07)	6.94 (0.65)	7.98 (0.35)
F2000	66.61 (2.37)	78.58 (6.08)	11.03 (0.42)	13.02 (0.47)
Filtek Flow	79.76 (6.63)	99.73 (3.26)	3.45 (0.41)	4.26 (0.44)

Standard deviations in parenthesis.

Table 3: *Comparison of Flexural Properties Between Materials*

Flexural Property	Storage Time	Differences
Strength	**1 week**	Z100 > all other composites
		Z250 > A110, F2000, Filtek Flow
		Filtek Flow > A110, F2000
	1 month	Z100 > all other composites
		Z250 > A110, F2000, Filtek Flow
		Filtek Flow > A110, F2000
Modulus	**1 week**	All other composites > Filtek Flow
		Z100, Z250, F2000 > A110
		Z100, F2000 > Z250
	1 month	Z100, Z250, F2000 > A110, Filtek Flow
		Z100, F2000 > Z250

Results of one-way ANOVA/Scheffe's test at significance level 0.05. > indicates statistically significant difference in flexural properties.

Table 4: *Comparison of Flexural Strength and Modulus Between the Two Storage Periods*

Materials	Flexural Strength	Flexural Modulus
A110	NS	NS
Z100	NS	S
Z250	S	S
F2000	S	S
Filtek Flow	S	S

Results of Independent Samples t-test at significance level 0.05. NS indicates no statistically significant difference while S indicates statistically significant differences in flexural properties.

Where

F_1/D is the slope, in newtons per millimeter, measured in the straight-line portion of the load-deflection graph;

L, B and H have been defined in the flexural strength equation.

Flexural modulus in MPa was subsequently converted to GPa. With the exception of correlation, all statistical analysis was conducted at significance level 0.05. Interactions between materials and aging period were determined using two-way ANOVA. Inter-material strength and modulus was compared using one-way ANOVA/post-hoc Scheffe's test and the effects of aging on flexural properties were assessed using Independent Sample's t-test. Pearson's correlation between flexural strength and modulus was conducted at significance level of 0.01.

RESULTS

The mean flexural strength and modulus of the various materials are shown in Table 2 and Figures 2 and 3. Results of statistical analysis are shown in Table 3 and 4. Mean flexural strength ranged from 66.61 to 147.21 and 68.74 to 142.69 MPa at one week and one month, respectively. Mean flexural modulus at one week and one month ranged from 3.45 to 11.30 and 4.86 to 13.02 GPa, respectively. At one week, ranking of flexural strengths from lowest to highest was as follows: F2000 < A110 < Filtek Flow < Z250 < Z100. Ranking of flexural strengths at one month was similar with the exception of the change in ranking between F2000 and A110 (A110 < F2000). The ranking of flexural modulus at one week was Filtek Flow < A110 < Z250 < F2000 < Z100. Ranking of flexural modulus at one month was similar with the exception of the change in ranking between F2000 and Z100 (Z100 < F2000).

Two-way ANOVA revealed significant interactions between materials and storage time. The effects of aging on flexural properties were therefore material dependent. Significant differences in flexural strength between materials were identical after aging for one week and one month. Z100 was significantly stronger than all other composites evaluated. The flexural strength of Z250 was significantly higher than A110, F2000 and Filtek Flow. In addition, Filtek Flow was significantly stronger than A110 and F2000. At both time periods, A110 and Filtek Flow were significantly more flexible than Z100, Z250 and F2000, and Z250 was more flexible than Z100 and F2000. Although A110 was stiffer than Filtek Flow at one week, no significant difference in flexural modulus was observed after one month. With the exception of A110, a significant increase in flexural modulus was observed with all composites. Although flexural strength of F2000 and Filtek Flow was significantly increased with aging in water, the flexural strength of Z250 was significantly decreased. The correlation between flexural strength and modulus was significant and positive with a correlation coefficient of r=0.34.

DISCUSSION

Flexural strength and modulus testing based on ISO 4049 is commonly employed in dental research (Iazzetti & others, 2001; Yap & others, 2000a; Azillah, Anstice & Pearson, 1998; Li & others, 1996). The 2 mm height advocated is the maximum dimension permissible for effective polymerization of composites (Yap, 2000). As light irradiation was done from top and bottom surfaces, optimal polymerization is expected. The maximum conversion from monomer to polymer in dental composites is, however, only in the range of 60-75% (Ruyter & Øysæd, 1987; Ferracane & Condon, 1990). Baseline testing was delayed for at least one week to allow for elution of all leachable, unreacted components and composite post-cure (Ferracane & Condon, 1990; Watts, Amer & Combe, 1987). The latter refers to the progressive cross-linking reactions in composites after light curing. Ferracane (1995) studied the effects of normal-cured and heat-cured composites after aging in water for 1 to 180 days. By 30 days, both types of composites showed significant reductions in mechanical properties including flexural strength and modulus. As aging had little effect after 30 days, a one-month aging period was selected for this study.

The flexural strength of all composites evaluated fulfilled the requirements specified in ISO 4049 (flexural strength > 50 MPa and mean flexural strength > [(mean flexural modulus x 0.0025) + 40] MPa). With the exception of F2000, flexural strength results can be attributed to the filler content of the composites. Studies have reported a positive correlation between the mechanical properties and volume fraction of fillers (Kim & others, 1994; Chung & Greener, 1990; Braem & others, 1989; Ferracane, Antonio & Matsumoto, 1987). Composites with higher filler volumes like Z100 and Z250 are therefore expected to be stronger than those with lower filler volumes. The significantly lower flexural strength observed with F2000, in spite of its high filler content, may be attributed to the use of fluoroaluminosilicate glass fillers and/or the CDMA oligomer. The latter is a methacrylated polycarboxylic acid. Most of the composites evaluated were based on zirconia silica fillers and BISGMA resin. Fluoroaluminosilicate glass fillers (the basic glass in glass ionomer cements) were incorporated into F2000 for fluoride release. Due to their relatively large particle sizes (3 to 10 µm), the total filler loading by volume is substantially increased. As both major constituents of F2000 are relatively weak, its flexural strength is expected to be lower than the other composites evaluated except A110. The low flexural strength of A110 could be attributed to its low filler (colloidal silica) content and the fact that the prepolymerized resin fillers are not well bonded to the polymer matrix (Ferracane, 1995). The resin fillers are heat-cured and do not form covalent chemical bonds with the polymerizing matrix due to the lack of available methacrylate groups on their surfaces. Therefore, they become debonded and dislodged under high stresses. The higher incidence of clinical fractures observed with microfill composites as compared to more heavily filled materials (Tyas & Wassenaar, 1991) might be partially attributed to their low flexural strengths. Due to their low flexural strengths, F2000, A110 and Filtek Flow are not indicated for stress-bearing restorations.

Results for flexural modulus can also be explained by differences in filler content. Increasing filler loading increases the stiffness of composites (Kim & others, 1994; Braem & others, 1989). The glass ionomer characteristics imparted by the chemical reaction between the methacrylated polycarboxylic acid and fluoroaluminosilicate glass fillers in F2000 may also contribute to its high flexural modulus. Flexural modulus appears to be a significant property in the retention of cervical restorations. In a clinical study, significantly more retention failures were associated with a high modulus composite that has high filler content (McGuckin & others, 1991). In the same study, microfill composites with lower modulus appeared to flex in response to cervical deformation rather than debonding. When more rigid composite materials are used, the shear stresses at the adhesive interface could exceed the compressive stresses, thus acting primarily on the dentin bond. The use of A110 and Filtek Flow is thus preferred over Z100, Z250 and F2000 for restoration of Class V cavities. The low flexural strength and high modulus of F2000 may limit its clinical usefulness. Long-term clinical studies pertaining to F2000 are currently not available. A clinical evaluation of F2000 placed in general practice reported a 2.4% failure rate after one-year (Crisp & Burke, 2000). Intact restorations were, however, found to be performing satisfactorily. Although the correlation between flexural strength and modulus was significant, it was not strong (r=0.34). An increase in flexural strength was associated with an increase in stiffness.

Two-way ANOVA revealed significant interactions between materials and storage time. The effects of aging in water on flexural strength and modulus were therefore composite dependent. Flexural properties obtained after aging is dependent on the balance between composite post-cure and the degradation by water (Yap & others, 2000a). Any increase in flexural strength and modulus can be attributed to additional cross-linking reactions of the resin component after light curing as the quantity of fillers, which increases physical properties, remains the same. The resin matrix of composites is known to absorb a small percentage of water, which changes the magnitude of some physical properties (Yap, Low & Ong, 2000b; Hansen, 1983). All composites evaluated contained silica or silicate glass fillers that have irregularly distributed Si-O-Si bonds. When the composites are immersed in water, the resin matrix swells and radial tensile stresses are introduced at the filler interfaces, straining the Si-O-Si bonds in the fillers. The high energy levels resulting from the strained Si-O-Si bonds make the fillers more susceptible to stress corrosion attack (Söderholm, 1983), resulting in complete or partial filler debonding. Hoop stresses also exist around the filler particles as a result of matrix shrinkage during polymerization (Söderholm, 1984). These hoop stresses increase the frictional forces between the filler and resin matrix, thereby decreasing the filler pull-out tendency during flexural testing. After aging in water, the plasticizing and swelling of the resin matrix reduces the hoop stresses around the fillers and facilitates filler pullout.

The aforementioned mechanisms might contribute to the decreased flexural strength observed with A110, Z100 and Z250 after aging for one month in water. Any positive effects obtained with composite post-cure are thus negated by water degradation. A significant decrease in flexural strength was, however, observed only for Z250. In Z250, the diluent TEGDMA is replaced with a blend of UDMA and BISEMA. These monomers have higher molecular weight and therefore fewer double bonds per unit of weight than TEGDMA. The higher molecular weight of UDMA/BISEMA and greater hydrophobicity of BISEMA (Ruyter & Nilsen, 1993) should theoretically reduce the effects of aging and lead to an increase or maintenance of flexural strength. Why Z250 causes a significant decrease in flexural strength is not known and warrants further investigation. Z250 having a shorter curing time (20 seconds) compared to A110 and Z100 may be a cause. This could result in lower monomer to polymer conversion and subsequent leaching of the unreacted monomers over time. Significant increases in flexural strength of F2000 and Filtek Flow may be attributed to the glass ionomer acid-base reaction and low filler loading, respectively. Kalachandra (1989) characterized the water sorption of dental composites in terms of water uptake, diffusion coefficients and polymer content to study how these parameters are influenced by fillers. When water sorption of filled specimens was compared to predictions of ideal systems based solely on polymer content, filled specimens were found to absorb twice as much water as the unfilled specimens. It was hypothesized that the filler-matrix interface, if uncoupled, provides paths of facile diffusion similar to grain boundary diffusion. A lower filler content may therefore lead to less accommodation of water at the interface between the fillers and matrix resulting in decreased water sorption and aging effects. Although A110 has low filler loading, the total interface between the fillers and matrix can be relatively large due to the use of micro and pre-polymerized resin fillers.

For all composites, an increase in stiffness was observed with aging. The increase in stiffness that can be attributed to post-cure was significant for all composites except A110. A substantial proportion of the resin in A110 is in the form of pre-polymerized resin fillers. As the resin in these fillers is heat-cured, there is greater conversion of monomer to polymer and minimal additional cross-linking after light curing. Although an increase in modulus is advantageous in stress-bearing situations, it may result in debonding of cervical restorations, as the lowest modulus of dentin reported in the literature is 10.1 GPa (Marshall & others, 1997).

CONCLUSIONS

Under the conditions of this *in vitro* study:

1. The effects of aging on flexural strength and modulus were material dependent.
2. The flexural strength of the minifill composite with BISEMA/UDMA diluent was decreased, while that of the polyacid-modified and flowable composites was increased with age.
3. A significant increase in flexural modulus was observed with all composites with the exception of the microfill composite.
4. The clinical durability of some composites may be compromised due to changes in flexural properties with aging.

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Quantitative Evaluation of Marginal Leakage of Two Resin Composite Restorations Using Two Filling Techniques

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Clinical Relevance

Medium-viscosity composites exhibited better marginal adaptation and less leakage when compared with high-viscosity composites in cavities filled with horizontal increments.

SUMMARY

This *in vitro* **study evaluated the marginal leakage of two light-cured resin composites used for posterior restorations using two filling techniques. Standardized Class V cavities were made on the enamel vestibular surface of 30 freshly extracted sound inferior bovine incisors. The teeth were randomly restored according to three experimental groups (Group 1—Z250 with 1 mm vertical increments; Group 2—Z250 with 1 mm horizontal increments; Group 3—SureFil with 1 mm horizontal increments). All samples were thermocycled (3000 cycles at 5°C and 55°C) with a dwell time of one minute at each temperature and immersed in a dye solution for 12 hours. After being ground into powder, the samples were individually immersed into glass tubes with absolute alcohol. The solution was centrifuged and the supernatant was analyzed using a spectrophotometer to quantify its dye concentration. Results showed that Group 2 exhibited the lowest leakage means, which was significantly different from Groups 1 and 3 ($p<0.05$). It was concluded that despite the lower leakage means exhibited by medium viscosity composites, no restorative material or filling technique was able to avoid leakage.**

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INTRODUCTION

Dental resin composite is the most frequently used direct tooth-colored restorative material. Improvements in mechanical properties have made posterior tooth restorations possible (Leinfelder, Bayne & Swift Jr, 1999; Manhart & others, 2000). After the development of new adhesive systems and the improvement of resin composite properties, aesthetic restorations have been commonly used for posterior teeth. Due to their high viscosity and better properties, the recent generation of composites have appeared on the market specifically for posterior teeth restorations. This material presents lower average wear, lower polymerization shrinkage, good mechanical parameters (Manhart & others, 2000) and better handling characteristics (Leinfelder & Prassad, 1998).

Polymerization shrinkage is still the main problem of resin composites (Friedl & others, 2000). Its shrinkage leads to some clinical problems, such as marginal discoloration, restoration fractures, solubility of the bonding system and marginal leakage. Leakage is characterized by a gap between the restoration and the tooth, through which acid, enzymes, ions, bacteria and bacterial metabolites can penetrate (Kidd, 1976). This phenomenon causes postoperative sensitivity, secondary caries, inflammation or even pulp necrosis (Gordon & others, 1986).

Many filling techniques have been developed to help minimize polymerization shrinkage. The most acceptable technique is to insert and cure this material in increments (Fisbein & others, 1988), which results in lower shrinkage in total polymerization and reduced stress over both the adhesive system and the surrounding cavity walls (Fisbein & others, 1988). The concept of incremental filling technique was introduced for deep restorations in large cavities to overcome the difficulty of light curing thick resin composite layers (Hyrabayashi, Hood & Hirasawa, 1993).

Incremental layering of composites has been suggested as a method of counteracting composite shrinkage and stress (Lutz, Krejci & Oldenburg, 1986; Burgess & others, 1999). This concept has been questioned due to its advantages over shrinkage reduction (Versluis & others, 1996; Köprülü, Gürgan & Önen, 1995; Mangum & others, 1994; Puckett & others, 1992). However, this technique improves other aspects such as density, adaptation, thoroughness of cure and hardness of the composite (Yap, 2000; Versluis & others, 1996; Tjan, Bergh & Linder, 1992). Thus, dentists should choose this technique when restoring deep cavities (Yap, 2000; Jedrychowsky, Bleier & Caputo, 1998; Versluis & others, 1996; Tjan & others, 1992; Wieczkowski Jr & others, 1988; Hassan & others, 1987).

This study evaluated the microleakage behavior of two composite restorations (Z250 and SureFil) using a horizontal incremental filling technique (SureFil and Z250) or a vertical incremental filling technique (Z250).

METHODS AND MATERIALS

In order to avoid damaged teeth, 30 sound, inferior extract bovine incisors were cleaned, polished and examined under a microscope (x4) within one week after extraction. All teeth were stored in distilled water at 5°C during the two weeks prior to restoration procedures.

Standardized square Class V cavities (3 mm) were prepared in the middle of the vestibular surface of each tooth using a #3100 diamond bur (KG Sorensen Ind Com Ltda-Barueri–São Paulo, Brazil). The cavities were made with a high-speed turbine using a standard cavity preparation device. The bur was changed after every five preparations. The cavities were rinsed for 10 seconds with air/water spray and dried for 10 seconds.

Prior to the restoration procedure, 35% phosphoric acid gel (ScotchBond-3M Dental Products, St Paul, MN 55144, USA) was applied for 15 seconds. The cavities were rinsed for 15 seconds and gently air-dried for 10 seconds. Two layers of adhesive resin (Single Bond, 3M Dental Products) were applied and light cured for 20 seconds. All samples were randomly restored according to the following groups (*n=10*) (Figure 1):

Group 1: Cavities were filled with medium viscosity composite (Z250 3M Dental Products) using 1 mm vertical increments.

Group 2: Cavities were filled with medium viscosity composite (Z250 3M Dental Products) using 1 mm horizontal increments.

Group 3: Cavities were filled with high viscosity composite (SureFil-Dentsply Int, Milford, DE 19963, USA) using 1 mm horizontal increments.

SureFil composite layers were light cured for 40 seconds and Z250 composite layers were light cured for 20 seconds. A Degulux Soft Start Curing Light device (Degussa–Hüls AG Hanau Germany) was used in the conventional polymerization mode at a continuous intensity of 620mW/cm^2.

All samples were stored in distilled water at 37°C for 24 hours and polished with flexible disks (Sof-Lex Pop-on, 3M Dental Products) under water spray. All samples were maintained in water at 37°C for 24 hours. They were then thermocycled 3,000 times (5 ± 2° C and

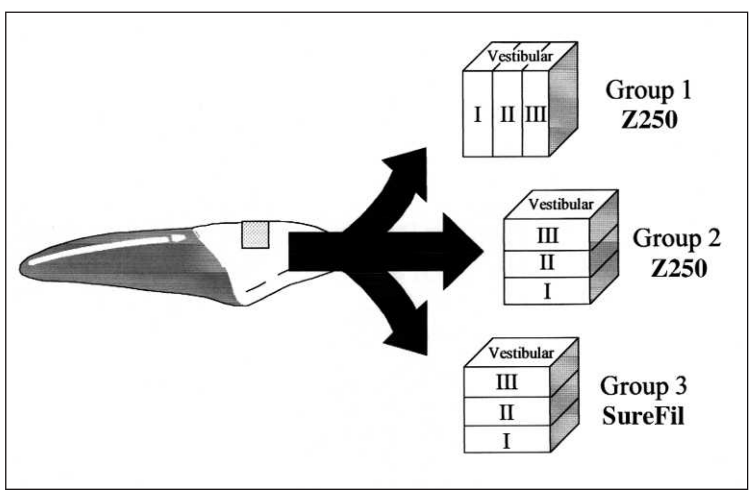

Figure 1. *Schematic representation of the restorative procedures.*

55 ± 2° C) with a dwell time of one minute at each temperature.

The apical roots were sealed with a composite (Tetric Ceram Ivoclar North America, Inc, Amherst NY 14228, USA) and a nail varnish was applied to the tooth surface, leaving out the restoration site and 1 mm of the adjacent area. All samples were immersed in a 2% methylene blue solution (Vip Formulas Ltda, Piracicaba Sao Paulo-13400 Brazil) at 37°C for 12 hours. All teeth were then rinsed in tap water and air dried. The nail varnish was removed with disks (Vicking-KG Sorensen Ind Com Ltda), and the restorations were polished with Sof-Lex disks in order to remove the superficial dye.

The crown of each tooth was set in acrylic plaques and placed in a precision saw (Imptech PC10-Equilam Lab Equip–Diadema-SP Brazil 09960-500) with two parallel diamond disks distanced 7 mm from each other and perpendicular to the tooth surface. Each tooth was cut in the incisal-gingival direction and the mesial-distal direction, forming a block. Dental blocks of 7 x 7 x 5 mm containing the restorations at the center were obtained.

The dye recovery method used to quantify the dye infiltration on the specimens was adapted from Douglas & Zakariasen (1981) and de Magalhães, Serra & Rodrigues Jr (1999). Each block was ground into powder in a mill for hard tissues (Marconi Equip Ltda, Piracicaba–SP, Brazil, 13400). The powder of each block was individually immersed in a glass tube containing 4 ml of absolute alcohol PA for 24 hours in order to dilute the methylene blue. The solutions were then centrifuged (Tomy–IC 15AN–Tomy Ind, Tokyo, Japan) at 3,000 rpm for three minutes. The supernatant was analyzed through a spectrophotometer (Beckman DU-65-Instruments, Inc, Fullerton, CA 92631, USA) adjusted with a wavelength of 668 nm.

To determine the absorbance, the spectrophotometer was adjusted with an appropriate wavelength for the methylene blue, corresponding to the maximum absorbency for the dye. To calibrate the spectrophotometer, the absorbance of standard solutions (0.1; 0.2; 0.3; 0.5; 1; 2; 4; 6 µg/mL) was determined at wavelengths ranging from 400 to 700 nm, and the maximum value was obtained at 668 nm. At this wavelength, the absorbances for the standard solutions were obtained. With these values, a coefficient of linear correlation (r=0.9998) and a straight-line equation (y=a+bx) were determined. To calculate the quantity of dye in dye concentration (µg/mL) that infiltrated between the tooth and the restoration, the "y" was changed for the absorbency value of each sample. Absorbances were plotted against concentration in a computer software (Excel for Windows-Microsoft Inc, CA 92121, USA).

The results of microleakage (µg/ml) were submitted to one-way ANOVA and Tukey tests at the 0.05 level of confidence.

RESULTS

To estimate the dye concentration on the experimental samples, a linear regression was obtained. The regression equation was expressed as: $y=0.2716x–0.0075$, where y is the absorbance and x is the dye concentration. The dye uptake of each specimen was expressed as µg dye/ml, with lower values indicating lower dye infiltration means. The correlation coefficient (r) was 0.9998.

Results of microleakage are presented in Figure 2. Group 2 exhibited the least leakage (0.0438 ± 0.0068) that was significantly different from Groups 1 (0.0825 ± 0.0124) and 3 (0.0659 ± 0.0115) ($p<0.05$). Group 1 showed the highest leakage means and was significantly different from Group 3 ($p<0.05$).

DISCUSSION

The main problem of posterior-teeth restorations using resin composites is polymerization shrinkage (Friedl & others, 2000). Volume reduction can affect the adhesion of the resin composite to the tooth structure (Lambrechts, Braem & Vanherle, 1987), influencing restoration longevity (Lambrechts & others, 1987), having a direct effect on leakage and causing tooth deformation (Jedrychowsky & others, 1998; Tjan & others, 1992). Shrinkage varies from composite to composite, but generally depends upon the filler quantity, diluent and monomer conversion rate (Burgess & others, 1999). With the exception of composite linear polymerization shrinkage, there are several factors influencing the marginal quality of restorations. Adhesive bond strength, restorative materials modulus of elasticity, cavity design, light intensity and curing time

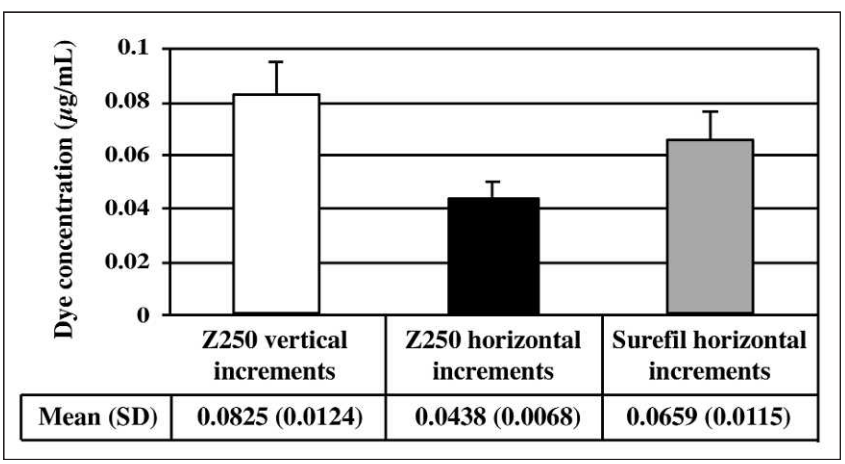

Figure 2. *Leakage mean (SD) of the three experimental groups.*

are some of the factors that influence the marginal quality of restorations (Unterbrink & Muessner, 1995; Friedl & others, 2000).

In this study, extracted bovine teeth were used because obtaining sound, extracted human teeth has become increasingly difficult due to recent progress in conservative dental treatment (Nakamichi, Iwaku & Fusayama, 1983). Although there are some limitations to using bovine teeth because of morphologic differences (Retief & others, 1990; Sydney-Zax, Mayer & Deutsch, 1991; Reeves & others, 1995), several studies have used bovine teeth as a substitute for human teeth. Histochemical and comparative anatomical studies have revealed that all mammalian teeth are essentially similar. Other studies have shown that there is not a statistical difference between human and bovine enamel and superficial dentin in relation to bond strength and microleakage (Nakamichi & others, 1983, Saunders, 1988; Reeves & others, 1995). In the current study, the cavity was made in enamel and the pulp wall was located in superficial dentin.

The quantitative method was used to determine the microleakage. The qualitative method does not take into account the density of the leakage in a three-dimensional leakage pattern. The spectrophotometric dye-recovery method used in this study allows for the direct quantitative measurement of leakage volumetrically (de Magalhães & others, 1999). Three groups were tested in this study. The medium viscosity composite (Z250-universal composite) was used in both types of incremental technique (vertical and horizontal) due to its lower viscosity. SureFil composite is a high viscosity material (Tyas, Jones & Rizkalla, 1998) and is a difficult procedure for the vertical technique. Thus, only the horizontal technique was used for this composite.

The lower leakage mean observed in restorations using horizontal increments could be explained by the compensation induced in the shrinkage by filling the gaps. In restorations with vertical increments, the last increment shows a bond area with cavity walls greater than the last one in restorations with horizontal increments. Therefore, the compensatory effect of the last vertical increment was lower in this group.

In addition, polymerization stress of the resin composite can also be associated with the cavity configuration (C-factor), which is the ratio between bonded and unbonded (free) surfaces (Feilzer, de Gee & Davidson, 1987). A lower unbonded area means less ability to flow, and therefore results in greater contraction stress in the bound surfaces (Carvalho & others, 1996). The C-factor of each horizontal increment in this study was approximately 2.33. While the C-factor of the two first increments of vertical filling was 1.5, the C-factor of the last increment was 9. Therefore, the stress of the final vertical increment was greater and could disrupt the integrity of the dentin-composite interface, thus, increasing the leakage.

Comparing the composites, results show that Z250 presented lower leakage means than SureFil. Despite SureFil's polymerization shrinkage (2.1%) (Leinfelder & others, 1999) being lower than Z250 (2.2%), the stress effect was minimized by the restoration technique used in this study. Thus, another factor that seems important is the initial adaptation of the composite prior to polymerization.

Although high-viscosity composite (SureFil) facilitates the dentist's handling, mainly to obtain the proximal contact and contour (Perry, Kugel & Leinfelder, 1999), this kind of composite presented inferior adaptation (before the polymerization). This may have occurred because this composite is composed of a blend of different sized fillers distributed on the matrix. When the composite is compressed mechanically, larger fillers interlock with smaller ones to achieve packability. In addition, the organic matrix was developed in order to limit the flow of the composite, which can make the perfect adaptation of the material to the cavity difficult, consequently, favoring marginal leakage.

This study evaluated the leakage of these composites. Other physical properties such as wear resistance of composites, compression strength, toughness and diametrical tensile strength were not studied. It is also important to notice that many factors must be considered before choosing an adequate restoration material.

CONCLUSIONS

Within the limits of this study, it can be concluded that:

1. No restorative material or filling technique could avoid leakage;
2. Medium viscosity composite resulted in lower leakage means when compared to high-viscosity composite restored using the horizontal technique;
3. The horizontal filling technique resulted in a lower leakage value when compared to the vertical filling technique.

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Extent of the Cariostatic Effect on Root Dentin Provided by Fluoride-Containing Restorative Materials

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Clinical Relevance

The extent to which fluoride is effective around a glass ionomer cement and a resin-modified glass ionomer are estimated to be about 0.3 and 0.15 mm, respectively, in root dentin. This could be important for reducing secondary root caries development.

SUMMARY

This study evaluated the extent of the cariostatic effect on root dentin provided by four fluoride-containing restorative systems: Ketac-Fil/ESPE [Ke], Fuji II LC Improved**/GC Corp [Fj], Dyract AP/Dentsply [Dy] and SureFil/Dentsply [Su], and one without fluoride: Z250/3M [control]. Ninety-five bovine root dentin fragments (5.0 x 6.0 mm) were obtained, embedded in polyester resin and planed. Cavities (1.5 x 3.5 x 1.0 mm) were made and restored by the five restorative systems (n=19) in a randomized complete block design according to the manufacturers' instructions. After 24 hours, the dentin/restoration surface was polished. The restoration surface and an adjacent area of 3.0 x 3.0 mm were demarcated and submitted to a pH-cycling model. Dentin surface Knoop microhardness values were obtained (5.0-g, 5.0-s) for 10 distances: 50, 100, 150, 300, 600, 900, 1200, 1500, 1800 and 2100 µm from the margin of the restoration. The dentin microhardness means for each restorative material at each distance was considered by the ANOVA multi-factor split-plot method. The interaction between the restorative system and distance was statistically significant (**$p<0.05$**). The Tukey test and the regression analysis showed that the means of [Ke] and [Fj] were similar up to 300 µm, the [Ke] means being higher than the [control] at distances 50, 100, 150 and 300 µm. The [Fj] means were higher than the [control] at distances 50, 100 and 150 µm. The microhardness means of [Dy] and [Su] were not statistically different from the [control] and remained steady throughout the studied distances. This study concluded that the extent of the cariostatic effect on root dentin was 300 µm for [Ke] and 150 µm for [Fj]. [Dy] and [Su] did not show any cariostatic effect.**

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INTRODUCTION

In vitro studies have shown that fluoride-containing restorative materials can inhibit the development of root surface caries adjacent to restorations (Tam, Chan & Yim, 1997; Pereira & others, 1998; Dionysopoulos & others, 1998; Torii & others, 2001). This effect is attributed to fluoride ions released from these materials that may act mainly by inhibiting dentin demineralization and/or by enhancing its remineralization process (Featherstone, 1994). In this way, the amount of fluoride released from the restoration probably explains the differences in *in vitro* secondary caries inhibition of various fluoride-containing restorative materials. Conventional glass ionomer cements (GIC) generally release an equivalent or higher amount of fluoride than resin-modified glass ionomers (RMGI), and both release more fluoride than polyacid-modified resin composites (PMCR) and fluoride-containing resin composites (FCR) (Suljak & Hatibovic-Kofman, 1996; Vermeersch, Leloup & Vreven, 2001).

However, the extent of the cariostatic effect on root dentin surface has not been evaluated. Although the use of fluoride-containing restorative materials is frequently indicated for preventing caries development at dental restoration margins, it is common to observe other sites of high risk of root caries through easy dental plaque accumulation (Erickson & Glasspoole, 1995), such as proximal root surfaces (Schüpbach, Lutz & Guggenheim, 1992) and root surfaces close to gingival margins (Lynch & Beighton, 1994). Therefore, can fluoride-containing restorations extend their cariostatic effect as far as this? There is evidence that glass ionomer cement not only prevents caries formation at the cavity wall but also inhibits lesion progression in enamel at a considerable distance from the restoration (Tantbirojn, Douglas & Versluis, 1997). Nevertheless, it is not known whether glass ionomer cement restorations placed in root dentin can also show their protective effect and, furthermore, whether other fluoride-releasing restorative materials, such as RMGI, PMCR and FCR are capable of behaving in the same way.

This *in vitro* study was designed to evaluate the extent of the cariostatic effect of five restorative systems: a glass ionomer cement, a resin-modified glass ionomer, a polyacid-modified resin composite, a resin composite with fluoride and a resin composite without fluoride (control), on root dentin surfaces adjacent to restorations. Specifically, this study tested whether there were any differences in dentin microhardness adjacent to restorative systems up to 2.1 mm from the restoration margin.

METHODS AND MATERIALS

Experimental Design

The factors under evaluation were restorative system at five levels (Table 1) and the cariostatic effect at 10 different distances from the restoration (50, 100, 150, 300, 600, 900, 1200, 1500, 1800 and 2100 µm). The experimental units were 95 root dentin fragments (n=19), restored in 19 blocks of five fragments each—one fragment for each restorative system. Within each block, the order in which the five materials were used to restore the fragments was randomly determined. A randomized complete block design was used to systematically control the variability arising from known nuisance sources (Montgomery, 1991). Since it was not possible to completely randomize the order of the distance level analysis, a randomization restriction was considered, utilizing a factorial 5 x 10 *split-plot* design (Montgomery, 1991). The three basic principles of experimental design: replication, randomization and blocking were employed (Montgomery, 1991). The con-

Table 1: *Restorative Systems Tested*

Brand Name	Type	Batch #	Manufacturer
Ketac-Fil Plus	GIC	Powder: FW0055787 Liquid: FW0056696 Ketac Conditioner: 0004	ESPE GmbH Seefeld, Germany D-82229
		Heliobond*: 0120598	Vigodent SA. Rio de Janeiro, RJ, 21041-150, Brazil
Fuji II LC *Improved*	RMGI	Powder: 160291 Liquid: 260191 GC Dentin Conditioner: 201241	GC Corporation Tokyo, Japan, 174-8585
		Heliobond*: 0120598	Vigodent SA Rio de Janeiro, RJ Brazil
Dyract AP	PMCR/AS	9904001505 Prime&Bond NT: 9811001097 H_3PO_4 34%: 990417	Dentsply Caulk Milford, DE 19963, USA
SureFil/Prime & Bond NT	FCR/FAS	990119 Prime&Bond NT: H_3PO_4 34%: 990417	Dentsply Caulk Milford, DE 19963, USA
Filtek Z250/Single Bond	CR/AS	9BX Single Bond: 9CY H_3PO_4 35%: 9PD	3M Dental Products St Paul, MN 55144, USA

**Used as surface protector.*
GIC=conventional glass-ionomer cement; RMGI=resin-modified glass-ionomer; PMCR=polyacid-modified composite resin; AS=adhesive system;

Table 2: *Restorative Techniques Used According to Manufacturers' Recommendations*

Restorative System	Dentin Pretreatment	Dispensing and Mixing	Insertion	Light Curing[6]	Surface Protection
Ketac-Fil *Plus*[1]	Ketac Conditioner[1]	Powder/Liquid ratio of 3/2 (g/g) Manually	Centrix Syringe[5]	None	Heliobond[7]
Fuji II LC *Improved*[2]	GC Conditioner[2]	Powder/Liquid ratio of 3/2 (g/g) Manually	Centrix Syringe[5]	20 seconds	Heliobond[7]
Dyract AP/Prime Bond NT[4]	H_3PO_4 34%[4] Prime & Bond NT Adhesive[4]	None	None	40 seconds	None
SureFil/Prime & Bond NT[4]	H_3PO_4 34%[4] Prime & Bond NT Adhesive[4]	None	None	40 seconds	None
Filtek Z250/Single Bond[3]	H_3PO_4 35%[3] Single Bond Adhesive[3]	None	None	30 seconds	None

[1]=Espe; [2]=GC Corp; [3]=3M Dental Products; [4]=Dentsply Caulk; [5]=Centrix Inc; [6]=Light intensity ranging from 550~600 mW/cm²; [7]=Vigodent.

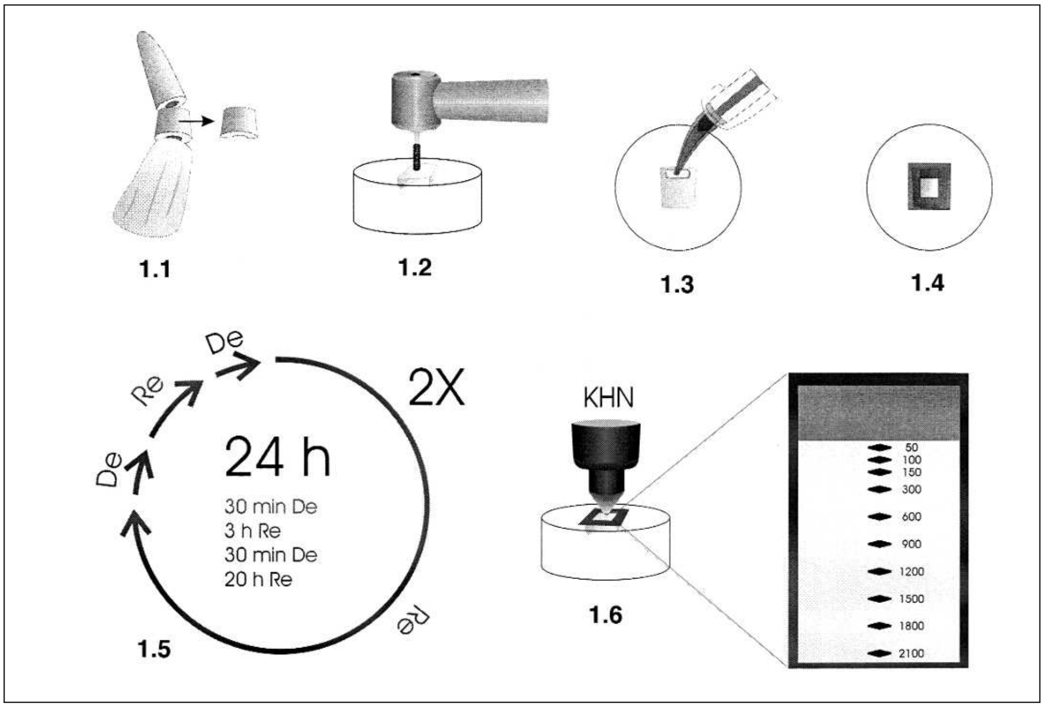

Figure 1.
1.1. Section of a bovine root dentin fragment.
1.2. *Cavity preparation (1.5 mm width, 3.5 mm length and 1.0 mm depth) in an embedded and sanded root fragment.*
1.3. Restoration procedures according to manufacturers' instructions.
1.4. Restoration (1.5 mm width x 3.0 mm length) and dentin (3.0 mm x 3.0 mm) surface areas left exposed to artificial caries development.
1.5. Artificial caries challenge based on pH-cycling model.
1.6. The indentations made at 10 distances to obtain the Knoop microhardness values.

tinuous quantitative response variable was the Knoop microhardness value.

Tooth Fragment Preparation

Ninety-five bovine incisor teeth were collected and stored in a 10% neutral buffered formalin solution until they were used. They were cleaned by means of a hand-scaler and a non-fluoride polishing paste. Defective root surfaces were discarded. The crown and the apical region of the root were cut off with a double-faced diamond disc (#7020-KG Sorensen, São Paulo, SP, Brazil) in a low-speed handpiece to obtain 95 root fragments with approximately 5.0 mm width, 6.0 mm length and 2.0 mm thickness (Figure 1.1). These fragments were embedded in polyester resin (5061 N-Cray Valley Ltda, Taboão da Serra, SP, Brazil) and sanded with a water-cooled mechanical grinder (Maxigrind-Solotest, São Paulo, SP, Brazil), using a #400, 600 and 1000-grit Al_2O_3 abrasive paper (Carborundum Abrasivos, Recife, PE, Brazil), in order to expose at least a 4 mm wide, 6 mm long area of dentin surface.

A cavity with a 1.5 mm width, 3.5 mm length and 1.0 mm depth was made using a diamond bur (#2096-KG Sorensen, São Paulo, SP, Brazil) in a high-speed handpiece (Dabi Atlante, Ribeirão Preto, SP, Brazil) under a constant water-spray coolant (Figure 1.2).

Restoration and Polishing Procedures

The prepared tooth fragments were restored according to the randomized complete block design. Nineteen blocks, each with five fragments, were made. The restorative techniques recommended by manufacturers were followed (Table 2) (Figure 1.3). The restored tooth fragments were individually immersed in artificial saliva at 37 ± 1ºC for 24-hours. After that, the restored surface was polished with a water-cooled mechanical grinder (Maxigrind Solotest, São Paulo, SP, Brazil) with #1000 Al_2O_3 abrasive paper (Carborundum Abrasivos, Recife, PE, Brazil). The restored tooth fragments were re-immersed in artificial saliva at 37 ± 1ºC, for 24-hours.

pH-Cycling Model

The dentin surfaces were covered with an acid resistant varnish (Colorama-CEIL, São Paulo, SP, Brazil), leaving an exposed area of only 1.5 mm width x 3.0 mm length of the restorations and an adjacent area of 3.0-mm x 3.0 mm of dentin surface (Figure 1.4).

The specimens were individually submitted to demineralizing (De) (2.0 mM Ca, 2.0 mM P in a buffer solution of 74 mM of acetate at pH 4.3) and remineralizing (Re) (1.5 mM Ca and 0.9 mM P in a buffer solution of 20.0 mM of Tris (hydroxymethil)-aminomethane at pH 7.0) solutions similar to that proposed by Featherstone & others (1986) and modified by Serra & Cury (1992) for enamel substrate. As dentin has a lower mineral content than enamel, it was necessary to pre-determine the number of cycles and the specimen immersion-time in each solution so that the Knoop surface microhardness after the artificial cariogenic challenge could be measured. This explains the choice of two 24-hour cycles: 30 minutes in De solution, three hours in Re solution, 30 minutes in De and 20 hours in Re (Figure 1.5).

Microhardness Assessment

The surface microhardness values (KHN) were obtained in a microhardness tester (HMV 2000-Shimadzu, Japan) with a Knoop diamond and a 5-g static-load that was applied for five seconds. Ten indentations were sequentially made at 50, 100, 150, 300, 600, 900, 1200, 1500, 1800 and 2100 µm from the margin of the restoration (Figure 1.6).

Statistical Analysis

A multi-factor analysis of variance (ANOVA) (α=0.05) for *split-plot* design was applied. A study of the interaction among the factors analyzed (restorative system, distance and block) was made. The interaction of particular interest was restorative system x distance. Multiple Comparisons Tukey test (α=0.05) was chosen to check differences in means within the factor distance, and a regression analysis was chosen to show the behavior along the distances within the factor restorative system. The analysis was performed with the SAS System 6.11 (SAS Institute Inc, Cary, NC 27513, USA) and the Curve Expert 1.3 (www.ebicom.net/~dhyams/cvxpt.htm) software.

RESULTS

The data did not present homogeneity of variances. In order to stabilize them, they were submitted to a reciprocal transformation (y=1/x).

The means (standard deviation) of the transformed Knoop microhardness values of each of the 50 groups (10 distances x 5 restorative systems) are given in Table 3. The ANOVA for *split-plot* showed a significant interaction between restorative system and distance (p=0.001). Within the factor distance, the Tukey test showed that Ketac-Fil and Fuji II LC had similar microhardness values up to the distance 300 µm. Ketac-Fil had higher microhardness values when compared to the control group (Z250), up to the distance 300 µm; and Fuji II LC differed from the control up to the distance 150 µm. Beyond these distances, both did not differ from the control. Dyract AP and SureFil did not differ from the control at any of the distances. For Dyract AP at the distances 600, 1200 and 2100 µm, the microhardness was significantly lower than the control. Only at distance 1800 µm did all restorative systems show no significant difference from each other.

Table 3: *Means and Standard Deviation of Transformed (y=1/x) Microhardness Values*

	50	100	150	300	600	900	1200	1500	1800	2100
Ketac-Fil	0.05092 A 0.01258	0.06153 A 0.01388	0.06747 A 0.01617	0.07647 A 0.01864	0.07983 A 0.01408	0.08255 A 0.01500	0.08495 A 0.01404	0.08283 A 0.01477	0.08586 A 0.01399	0.09019 AB 0.01387
Fuji II LC	0.05692 A 0.01443	0.06385 A 0.01451	0.06911 A 0.01700	0.07774 AB 0.01242	0.08028 A 0.01299	0.08323 AB 0.01418	0.08463 A 0.01433	0.08440 A 0.01437	0.08500 A 0.01477	0.08670 A 0.01507
SureFil	0.08085 B 0.01808	0.08345 B 0.01511	0.08584 B 0.01616	0.08968 B 0.01588	0.08964 A 0.01731	0.09416 BC 0.01169	0.09156 AB 0.01739	0.09181 AB 0.01581	0.09000 A 0.01854	0.09136 AB 0.01760
Z250	0.08591 BC 0.01398	0.08408 B 0.01500	0.08940 B 0.01298	0.08816 B 0.01503	0.08777 A 0.01672	0.08772 ABC 0.01781	0.08656 A 0.01689	0.08890 AB 0.02124	0.08580 A 0.02116	0.08682 A 0.01943
Dyract AP	0.09242 C 0.01113	0.09147 B 0.01119	0.09145 B 0.01062	0.09126 B 0.01435	0.09574 B 0.01249	0.09720 C 0.01057	0.09780 B 0.01158	0.09546 B 0.01308	0.09675 A 0.01359	0.09859 B 0.01251

Statistical differences are expressed by different letters following the means, in COLUMNS (p<0.05).
lsd=0.0109653.

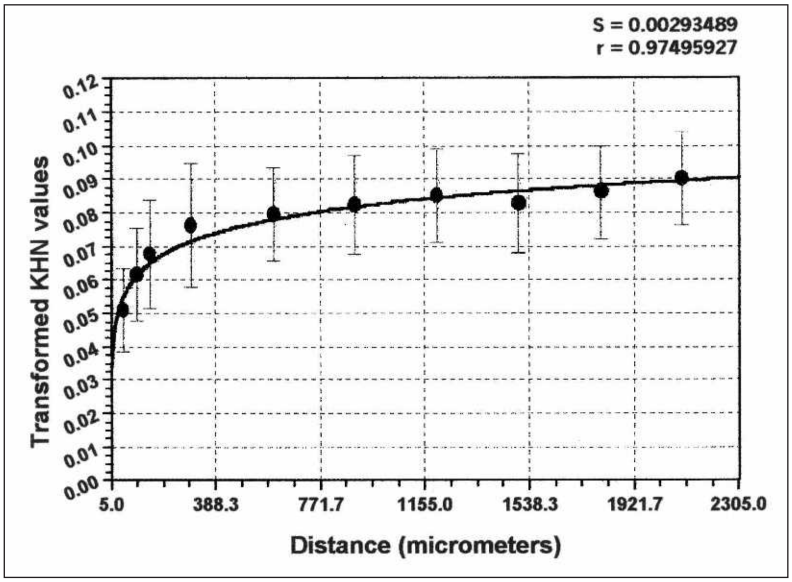

Figure 2. *The transformed microhardness values of Ketac-Fil were fitted according to a logarythm function (y=0.0192+0.0091l nx).*

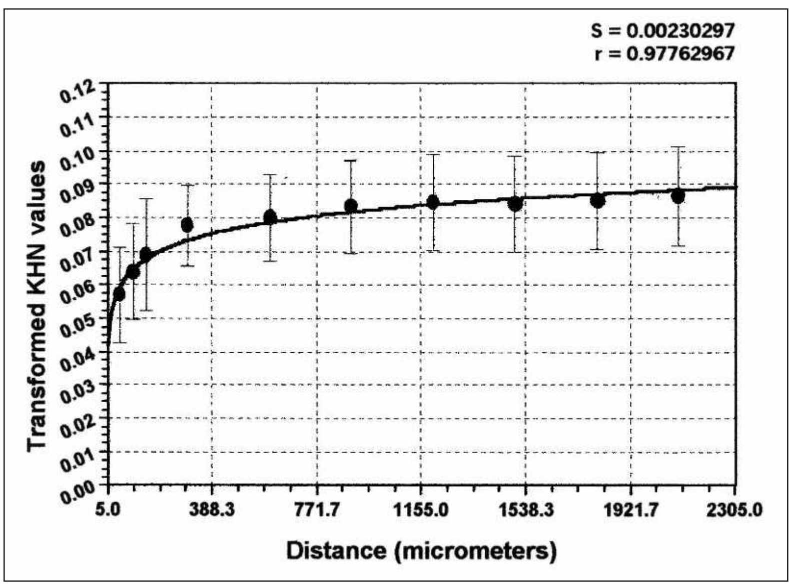

Figure 3. *The transformed microhardness values of Fuji II LC were fitted according to a logarythm function (y=0.0297+0.0076l nx).*

Within the restorative system, regression analysis allowed the characterization of behavior for each restorative system along the distances from the restoration margins. Ketac-Fil and Fuji II LC had similar behavior, which can be represented by logarithmic curves (y=0.0192 + 0.0091*lnx, r=0.97; and y=0.0297 + 0.0076*lnx, r=0.97, respectively), with high microhardness values close to the restoration (Figures 2 and 3). SureFil behavior could also be represented by a logarithmic curve (y=0.0713 + 0.0028lnx, r=0.89), however, with visually lower microhardness values than Ketac-Fil and Fuji II LC at close distances (Figure 4). For Dyract AP the best curve to explain its behavior was the linear (y=0.0919 + 3.28e-006x, r=0.85) (Figure 5). For Z250 a linear curve was also adjusted (y=0.0870 + 5.61e-008x) but there was no causal relationship between microhardness and distance (r=0.02) (Figure 6).

DISCUSSION

Fluoride-releasing restorative materials, such as GIC, RMGI and PMCR, have shown caries inhibition capacity in laboratory studies (Tam & others, 1997; Pereira & others, 1998; Dionysopoulos & others, 1998; Millar, Abiden & Nicholson, 1998), however, they have not confirmed this behavior in clinical trials (Levy & others, 1989; Kaurich & others, 1991). Thus, it has not yet been proven that fluoride-releasing restorative materials are capable of preventing secondary caries (Erickson & Glasspoole, 1995; Randall & Wilson, 1999). Several aspects should be considered in order to try to explain this fact and, within them, the extent of the cariostatic effect can be evidenced. Clinically, the cariostatic effect just close to the edge of the restoration may not be sufficient to prevent secondary caries development. Apart from the presence of the restoration, other factors can also contribute to increasing the risk of root caries adjacent to restorations, such as the nearness to gingival margins and/or to proximal surfaces (Erickson & Glasspoole, 1995; Mjör & Toffenetti, 2000). Since secondary caries occurs by the development of cariogenic conditions adjacent to restorations (Thylstrup, 1998), it is important to study not only the cariostatic effect just at the dentin margin of the cavity, but also on dentin surfaces along the margins of restorations.

Differences among restorative systems were evaluated at 10 distances along the restoration margin. The dentin microhardness values adjacent to Ketac-Fil were higher than the control up to a distance of 300 µm. For Fuji II LC the higher microhardness values were observed only at distances 50, 100 and 150 µm. Probably, the rate of fluoride ions released may explain this result, since previous studies have shown that Ketac-Fil releases more fluoride than Fuji II LC (Vermeersch & others, 2001).

SureFil behaved in the same way as the control along all distances. The ability of SureFil to inhibit artificial caries development was not observed. This could be explained by the relatively low fluoride ion release from fluoride-containing resin composites to the surrounding oral micro-environment (Erickson & Glasspoole, 1995; Arends, Dijkman & Dijkman, 1995; Karantakis & others, 2000). The dentin microhardness values adjacent to

Dyract AP were similar to the control but at distances 600, 1200 and 2100 µm, they have an unexpected behavior, being statistically lower than the control Z250. Some cariostatic effect was expected for Dyract AP since in demineralizing and remineralizing solution the water-free acid group components are expected to ionize and interact with the basic glass components, developing an acid-base reaction with fluoride release (Eliades, Kakaboura & Palaghias, 1998; Meyer, Cattani-Lorente & Dupuis, 1998). However, Dyract AP performed equally or worse than the control group. This result did not confirm that reported in the literature, where Dyract AP demonstrated some caries inhibition effect *in vitro* (Dionysopoulos & others, 1998; Millar & others, 1998).

Beyond the distance 300 µm, it was presumed that all groups of restorative materials would behave in the same way, but this occurred only at distance 1800 µm. The unexpected behavior of Dyract AP contributed to this since Ketac-Fil, Fuji II LC and SureFil did not differ from the control after the distance 300 µm.

Regression analysis helped to explain the behavior of dentin microhardness response as a function of distances according to mathematical models. Logarithmic curves (Figures 2, 3 and 4) allow the supposition that higher amounts of fluoride released from the restorations may interfere with caries development in dentin close to the restorative material. Thus, higher microhardness values could be observed at initial distances in the Ketac-Fil and Fuji II LC graphs. For SureFil the microhardness values were not highly pronounced close to the restoration. Probably this material had a low cariostatic effect that was not evidenced at the distances analyzed in this study. The absence of statistically significant differences between SureFil and the control at all distances confirm this finding. Throughout distances, the microhardness values dropped until they established a constant level, where, presumably, the fluoride cannot extend its effect.

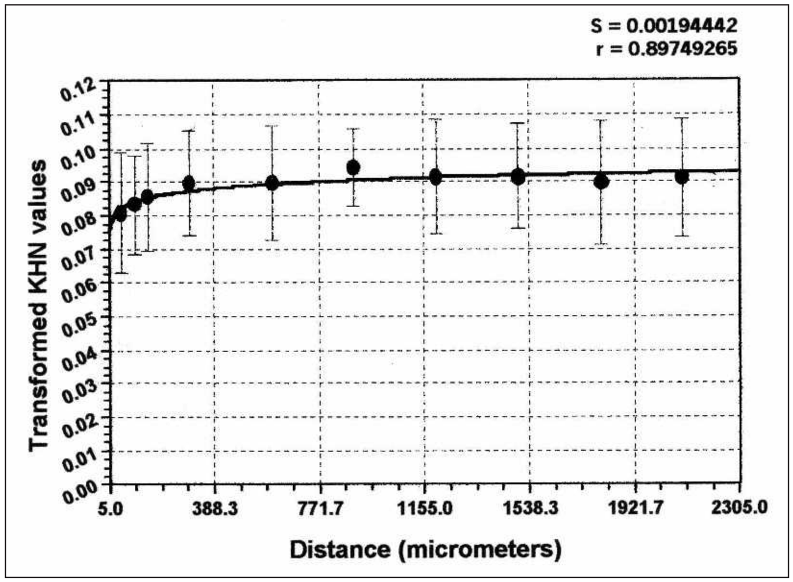

Figure 4. *The transformed microhardness values of SureFil were fitted according to a logarythm function (y=0.0713+0.0028l nx).*

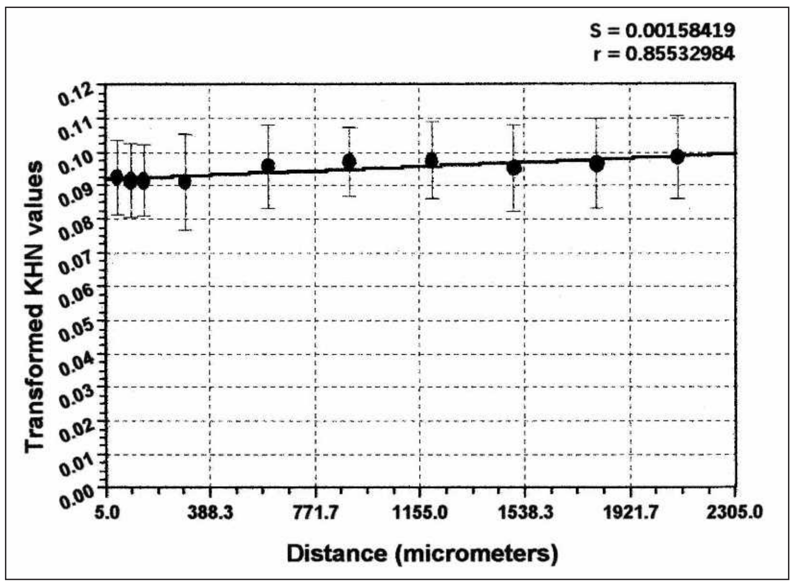

Figure 5. *The transformed microhardness values of Dyract AP were fitted according to a linear function (y=0.0919+3.28 e-006 x).*

Linear curves were adjusted for Dyract AP (Figure 5) and Z250 (Figure 6). For the latter a low correlation coefficient was obtained (r=0.02), showing no correlation between microhardness and distance. However, the aspect of plotted data allowed the supposition that the microhardness of dentin adjacent to Z250 remained steady throughout the distances in this study. For these materials it was concluded that fluoride could not influence dentin microhardness by inhibiting demineralization and/or enhancing remineralization processes.

In fact, Ketac-Fil and Fuji II LC showed an extent of cariostatic effect, that is they were capable of inhibiting artificial caries development beyond the restoration margins. However, this *in vitro* study did not entirely reproduce clinical conditions of cariogenic challenge. The effects of dental plaque—as a mechanical barrier (Erickson & Glasspoole, 1995)—and of saliva—as a fluoride disperser by continual replenishment (Erickson & Glasspoole, 1995; Tantbirojn & others, 1997)—were not considered in this study, and they seem to be related to the extent of cariostatic effect. Further studies reproducing clinical conditions are necessary to confirm the

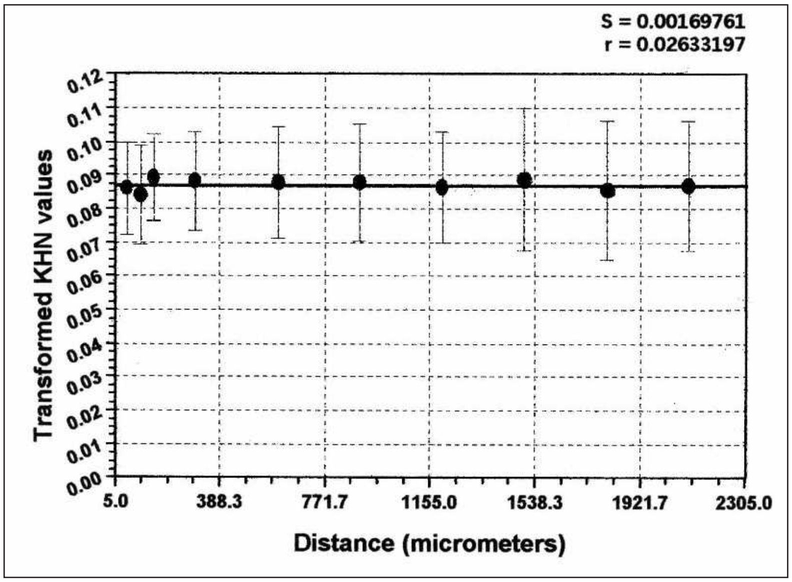

Figure 6. *The transformed microhardness values of Z250 were fitted according to a linear function (y=0.0870+5.61 e-008 x).*

findings obtained in this work. *In situ* models appear to be a good option. However, the results obtained in this study are useful for distinguishing the cariostatic effect among different fluoride-containing restorative systems.

Another interesting aspect to be considered is that this analysis was performed four days after the restorations were made. Although various fluoride-containing restorative materials have different rates and durations of fluoride release, most of the major fluoride release usually occurs within the first seven days (Hsu & others, 1998; Vermeersch & others, 2001). Thus, the fluoride effect might be amplified by the experimental conditions. A study will be carried out to evaluate the extent of the cariostatic effect of aging restorations.

To answer the question that encouraged the initiation of this study, Dyract AP and SureFil did not show a cariostatic effect. The extent to which fluoride was effective around Ketac-Fil and Fuji II LC was estimated to be about 300 and 150 µm, respectively. Although this extent could not be large enough to prevent root caries far from a restoration, it is important for reducing secondary root caries development close to the restoration margin.

CONCLUSIONS

The extent of the cariostatic effect on root dentin was 300 µm for Ketac-Fil and 150 µm for Fuji II LC *Improved*. Dyract AP and SureFil did not show any cariostatic effect.

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Survival Analysis of Posterior Restorations Using an Insurance Claims Database

RE Bogacki • RJ Hunt
M del Aguila • WR Smith

Clinical Relevance

This study indicates that composite restorations do not last as long as amalgam restorations in posterior teeth. Dentists can use this information to better inform their patients when choosing restorative materials.

INTRODUCTION

Over the past decade, resin composite has become increasingly popular as an alternative to amalgam for restoring posterior teeth (Anderson, 2001). Figure 1 shows patients in the Washington Dental Service have received an increasing number of resin composite restorations each year since 1993. Composite usage exceeded amalgam beginning in 1999 and continued through December 2000. Several factors may contribute to this increase in use of resin composite. Patients may be asking for composite because of its tooth-colored appearance (Dietschi & Dietschi, 1996). Dentists may believe that composite is better in many clinical situations (Wiggins, 2001). There may be a growing fear of mercury present in amalgam (Roulet, 1997). In any case, based on current trends, composite's popularity will probably continue to rise.

Previous studies suggest that the average amalgam restoration longevity is 10-12 years and resin composite's longevity is about half that time (Leinfelder, 2000). These estimates of survival are based on studies conducted between 1977 and 1989. However, resin composites have improved considerably since 1989 in terms of properties, handling and longevity. This study determined whether the choice of material used to restore a posterior tooth had an effect on the survival of the restoration.

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METHODS AND MATERIALS

Data Source

Data for this study came from the Seattle-based Washington Dental Service (WDS), a member of the Delta Dental Plans Association. Washington Dental Service has a claim-based data warehouse that has stored data longitudinally since 1993. The data warehouse is updated monthly and contains data on dental services provided to approximately 650,000 primary subscribers and 1.5 million patients. Specific elements include information related to treatment, provider-specific information (that is, specialty, date of graduation, number of clinics) and patient-specific information and data related to the purchaser. The sample of data used in this study included the dental care services provided on the dates from 1 January 1993 until 30 June 2000.

Study Design

This was an inception cohort study of adult patients who received either an amalgam or composite multi-surface posterior restoration between 1 January 1993 and 31 December 1999. Each patient contributed only one multi-surface posterior restoration in order to maintain independent data (Aalen, Bjertness & Soonju, 1995). Every restoration had to include the occlusal and at least one other tooth surface. The study end date was 30 June 2000, which ensured that all patients had a chance of being followed for at least six months.

A restoration failed if it was replaced by another restoration with the same tooth surfaces. A

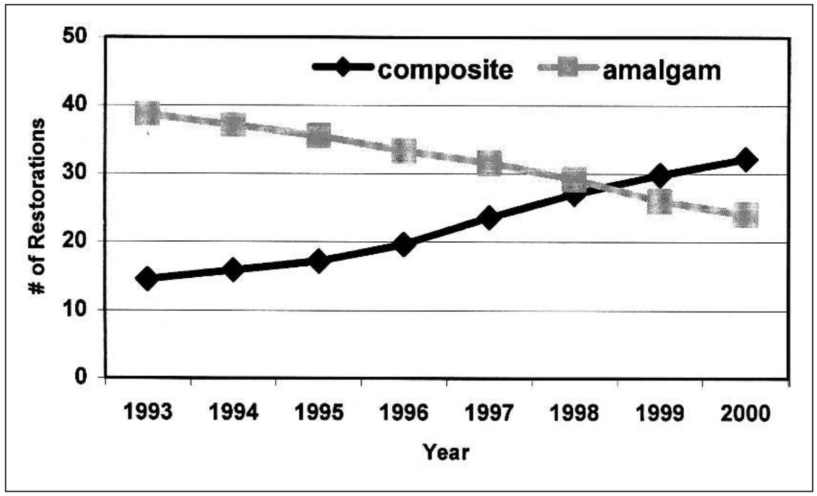

Figure 1. *Number of restorations per 100 patients per year. (Source: Washington Dental Service, Seattle)*

Table 1: *Sample Size and Description: A = Amalgam C = Composite*

Year	1993		1994		1995	
Characteristic	**A**	**C**	**A**	**C**	**A**	**C**
Sample Size	4,455	1,141	46,494	11,605	41,587	12,663
% Female	46%	58%	48%	60%	48%	59%
Average Patient Age	37	34	39	36	40	38
Average Provider Age	45	46	46	47	47	47
Average Follow-up Time (Months)	70	70	65	65	54	55
# of 2 Surface Restorations	1,909	673	19,779	6,719	17,509	7,143
# of 3 Surface Restorations	1,756	445	18,611	4,714	16,547	5,257
# of 4+ Surface Restorations	790	23	8,104	172	7,531	263
Year	**1996**		**1997**		**1998**	
Characteristic	**A**	**C**	**A**	**C**	**A**	**C**
Sample Size (300,753)	38,246	15,122	34,513	18,272	22,311	15,963
% Female	47%	58%	47%	57%	44%	55%
Average Patient Age	40	37	41	37	40	36
Average Provider Age	48	48	48	48	48	48
Average Follow-up Time (Months)	48	44	34	33	22	22
# of 2 Surface Restorations	16,035	8,723	14,467	10,464	8,955	9,015
# of 3 Surface Restorations	15,197	6,074	13,418	7,357	8,682	6,517
# of 4+ Surface Restorations	7,014	325	6,628	451	4,674	431
Year	**1999**		**Total**			
Characteristic	**A**	**C**	**A**	**C**		
Sample Size (300,753)	19,952	18,429	207,558	93,195		
% Female	45%	54%	47%	57%		
Average Patient Age	40	37	40	37		
Average Provider Age	49	48	47	48		
Average Follow-up Time (Months)	12	11	44	36		
# of 2 Surface Restorations	8,264	10,327	86,918	53,064		
# of 3 Surface Restorations	7,692	7,543	81,903	37,907		
# of 4+ Surface Restorations	3,996	559	38,737	2,224		

Table 2: *Partial List of Likelihood Ratio Test Results*

				Test Details			
	Model	Delta vs Null	df	Delta	df	p-value	Effect Tested
1	restoration type	31.7117	1	31.7117	1	<0.0001	restoration type
2	prior restoration history	239.9177	2	239.9177	2	<0.0001	previous one year restorative history
3	provider age	48.6345	5	48.6345	5	<0.0001	provider age categories
4	patient age	1697.5386	5	1697.5386	5	<0.0001	patient age categories
5	tooth location	572.8515	3	572.8515	3	<0.0001	tooth location categories
6	year of treatment	254.9478	6	254.9478	6	<0.0001	year of treatment
7	change of provider	14665.4389	1	14665.4389	1	<0.0001	change of provider
8	restoration type + change of provider	14695.6586	2	14663.9469	1	0.0000	change of provider | restoration type (model 1)
				30.2197	1	0.0000	restoration type | change of provider (model 7)
9	model 8 + interaction of restoration type and change of provider	14704.2678	3	8.6092	1	0.0033	interaction of restoration type and change of provider | model 8

Table 3: *Hazard Ratios (95% confidence intervals) by Restoration Type and Change of Dentist*

Restoration Type	Dentist change between index restoration and replacement.	
	yes	no
amalgam	1	1
composite	1.058 (1.014,1.103)	1.164 (1.118,1.212)

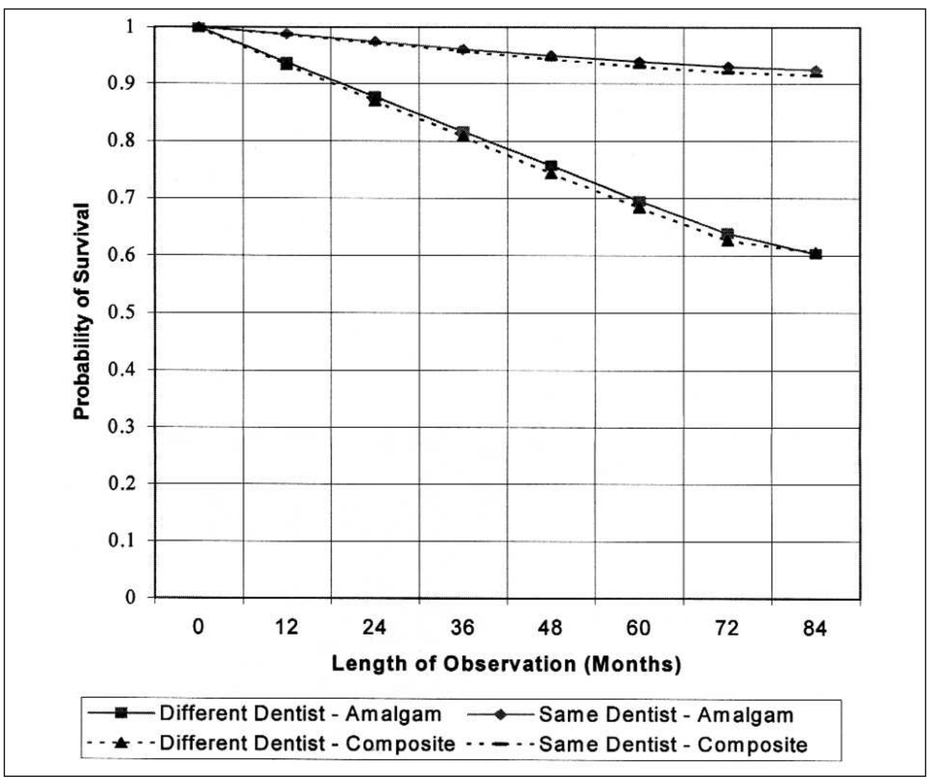

Figure 2. *Survival curves comparing amalgam with composite for patients who changed dentists and patients who stayed with the same dentist.*

restoration was censored if the tooth received a larger restoration, crown, endodontic treatment or was extracted. Restorations were also censored if patients received no additional treatment on that same tooth by the end of follow-up or at the time of discontinuation of WDS coverage. Each patient was followed until the restoration was censored or failed.

Data Management and Analysis

Data management and analysis used SAS versions 8.0 and 8.1. The outcome variable of interest was restoration longevity, defined as the time from index restoration placement until failure or censorship. The potential predictor variables studied were patient gender, age, dentist age, tooth location, prior restorative history, year of treatment, change of dentist and restoration material type. Prior restorative history was defined as the number of restorations the patient received in the year prior to entering the study. Tooth location was made discrete with four categories based on maxillary or mandibular, molar or premolar teeth. The reference category was the maxillary molar. Dentist age and patient age were made categorical by decade with the third decade of life as the reference category. Univariate Cox proportional hazard (PH) models were used to test the association between each predictor variable and restoration longevity (Woodward, 1999). All statistically significant variables were included in the multivariate Cox PH model and tested for significance. Variable and model significance was tested using likelihood ratio tests. The proportional hazards assumption was checked using a log cumulative hazard plot.

RESULTS

Sample Size and Description

Of the 300,753 patients included in this study, 207,558 (69%) had amalgam restorations placed and 93,195 (31%) had resin composite restorations placed. Patients with amalgam restorations were observed for an average of 44 months, and those with composite restorations were observed for an average of 36 months. Table 1 presents a more detailed description of the sample.

Variables Associated with Restoration Longevity

In the univariate Cox PH models, restoration type, prior restorative history, dentist age, patient age, tooth location, year of treatment and change of dentist were statistically significantly associated with restoration longevity ($p<0.0001$). In addition, the multivariate model showed the interaction between restoration type and change of dentist to be statistically significant ($p<0.0033$). A partial list of the likelihood ratio test results is presented in Table 2. Of all the variables tested, only patient gender was not statistically significant. All other variables tested were significant and were retained in the final model. Table 3 presents a list of the estimated hazard ratios associated with restoration type, estimated separately by change in dentist.

Survival Curves

Kaplan Meier graphs are used to illustrate the probability of restoration survival to a given point in time. Figure 2 compares amalgam with composite for patients who stayed with the same dentist versus patients who changed dentists. This figure shows that the probability of survival is always slightly higher for amalgam throughout the follow-up. Amalgam for a patient who stayed with the same dentist had a probability of 0.94 of surviving five years, while composite had a probability of 0.93. For patients who stayed with the same dentist, the probability that their restoration would survive seven years was about 0.92. For patients who saw a different dentist, the probability of survival was about 0.60. The probability of survival was much lower when the patient changed to a different dentist.

DISCUSSION

The estimated hazard ratio for restoration type when the patient stayed with the same dentist was 1.164 (95% confidence interval, 1.118-1.212). The interpretation of this ratio is that a patient with a composite restoration had a 16.4% greater chance of restoration failure at any given time than if they had an amalgam placed. The confidence interval indicates that the probability of failure could have been as much as 21.2% higher or as little as 11.8% higher. This hazard ratio shows that amalgam survives significantly longer than composite, controlling for prior restoration history, dentist age, patient age, tooth location and year of treatment (Hosmer & Lemeshow, 1999). These results agree with previous studies of restoration survival, although the magnitude of difference is less than generally observed (Papathanasiou, Curzon & Fairpo, 1994).

The estimated hazard ratio for restoration type where the patient saw a different dentist at the follow-up visit was 1.058 (95% CI, 1.014-1.103). This lower hazard ratio implies that composite has a lesser chance of failure compared to amalgam when the patient goes to a different dentist. This was caused by the strong effect a dentist change had on restoration survival as illustrated in Figure 2. Both composite and amalgam had a much greater chance of failure when the patient changed dentists. Previous studies have shown that dentists have a high level of variability in their diagnostic decisions, which may help explain this effect (Rytoma, Jarvinen & Jarvinen, 1979; Bader & Shugars, 1993). Moreover, coverage policies for people insured through Washington Dental Service entitles patients to restoration replacement within two years if they change dentists.

A restoration was deemed to have failed if it was replaced by another restoration with the same surfaces. This does not mean that the restoration definitely failed. Patients may have had their amalgams replaced with composite for esthetic reasons or a fear of mercury. Dentists may have deemed the composite a failure because of a small marginal stain. Therefore, at least part of the failure in this study may actually be replacement.

The limitation of using insurance claims data is the lack of control over experimental conditions. For example, there was no control over what material was used, how the material was used or when a restoration was considered a failure. This equation is further compounded by the ever-changing formulations of resin composite. While these limitations may appear to be weaknesses, they should also be considered strengths because they represent real-world dentistry. Each dentist has his or her own approach to care and each patient has different oral habits, diets and caries susceptibility. These data represent the true complexity of what occurs daily in dental offices.

CONCLUSIONS

This study determined whether the material used to restore a posterior tooth, either composite or amalgam, had a significant affect on the survival of that restoration. The results show that in a broad population of insured adults a restoration had a statistically significant greater chance of failing if it was resin composite. The results also show that composite fared almost as well as amalgam. Given these results, dentists should advise their patients that composite might not last as long as amalgam in a posterior tooth but is a good alternative to amalgam.

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Micromorphological Study of Resin-Dentin Interface of Non-Carious Cervical Lesions

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Clinical Relevance

There is little difference between bonding to dentin of non-carious cervical lesions (NCCL) and normal dentin. The hybrid layer thickness is less for NCCL, which may influence the longevity of the bond.

SUMMARY

This study examined the interfaces between two dentin adhesives, namely, One Coat Bond, Clearfil SE Bond and a resin-modified glass ionomer cement (Fuji II LC) and the dentin of non-carious cervical lesions (NCCLs) with FE-SEM, and compared them with the interfaces produced with "normal" dentin. Fifteen human premolars each with a buccal NCCL were used. Cervical cavities were prepared on the lingual surface of the same teeth for the normal (control) dentin. All lesions and prepared cavities were cleaned with a slurry of pumice and water. The teeth were randomly divided among the three products that were applied according to the manufacturers' instructions. For the resin-bonded specimens, the cavities were restored with resin composite. All specimens were stored in 37°C tap water. Resin-bonded specimens were observed using FE-SEM after treatment with 10% phosphoric acid, and 10% phosphoric acid and 5% sodium hypochlorite (NaOCl). The resin-modified glass ionomer cement (RM-GIC) specimens were observed after 10% phosphoric acid and 5% NaOCl treatment. The hybrid layer could be observed for the two adhesive systems in all specimens, but the thickness varied depending on the bonding system used and the dentin substrate. The results suggested that the hybrid layer produced in normal dentin was slightly thicker than that of NCCLs. Further, the hybrid layer thickness decreased in all specimens after NaOCl treatment.

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INTRODUCTION

Non-carious cervical lesions (NCCLs) are defects in the cervical third of teeth. The etiology of these lesions has been extensively reviewed (Levitch & others, 1994; Spranger, 1995; Tyas, 1995), and the classical factors associated with NCCL are attrition, "erosion" (correctly, corrosion) and abrasion. In addition, occlusal stress has also been proposed as an etiological factor since many NCCLs are observed on single teeth with adjacent teeth remaining intact (Lee & Eakle, 1984).

Bonding to dentin is based on micromechanical interlocking resulting from infiltration of adhesive resin into demineralized dentin. This resin-reinforced dentin is referred to as the "hybrid layer" or resin-dentin inter-diffusion zone (Nakabayashi, 1985; Van Meerbeek & others, 1992). Dentin bonding systems that link resin composite to the dentin now come in a variety of forms. Conventional adhesive systems generally include three components; a demineralizing agent, a primer and an adhesive, and require at least three steps. During the last few years, several new adhesive systems have been developed to simplify the bonding procedures. First, "one-bottle" adhesive systems combine the primer and adhesive into one application, preceded by a separate etching step. Vargas, Cobb & Denehy (1997) revealed that the hybrid layer created by the one-bottle systems used in their study was similar in morphology and depth to that of the conventional three-step system when etching was performed with a similar concentration of phosphoric acid and equal etching time. Second, "self-etching priming systems" combine etching and priming into a single step. A self-etching primer containing 10-methacryloyloxydecyl dihydrogen phosphate (MDP) partially dissolved the smear layer, allowing monomers to penetrate into the dentin and create a hybrid layer, resulting in good adhesion to dentin (Hayakawa, Kikutake & Nemoto, 1998).

Glass ionomer cements (GICs) have traditionally been used to restore NCCLs because of their adhesion to tooth structure and release of fluoride (Fritz, Finger & Uno, 1996; Maneenut & Tyas, 1995). The possible disadvantages of conventional (self-cured) GICs include initial sensitivity to moisture, poor wear resistance, low fracture toughness and high opacity (Sidhu, 1993; Wilson, 1990). Resin-modified GICs (RM-GIC) were developed to overcome the shortcomings of conventional GICs. In these materials, the setting reaction is a dual process; the fundamental acid-base reaction and a self-and/or light-induced polymerization of resin monomers, for example, hydroxyethyl methacrylate (HEMA). The RM-GICs have a good working time with a sharp set by light-activated polymerization, better mechanical properties than conventional GICs, and are resistant to early moisture contamination and desiccation (Wilson, 1990).

This study examined the morphology of the interface generated by three dentin adhesives and an RM-GIC on the dentin of NCCLs and compared it with the morphology of the interface produced on normal dentin in a similar region. The hypotheses tested are that there is no difference in ultrastructure of the hybrid layer of normal dentin and of NCCLs, and that there is no difference in such structure after NaOCl treatment.

METHODS AND MATERIALS

Fifteen human premolars with buccal NCCLs between 1.5 and 2 mm deep and approximately 2 to 2.5 mm in the inciso-apical direction and extracted for periodontal reasons were used. The premolars were stored in normal saline containing 0.1% thymol at 4°C for a maximum of two months. All lesions exhibited hard, smooth surfaces and none were discolored. For the control surface, cervical cavities were prepared at the cemento-enamel junction on the lingual surface of the same teeth using a high-speed medium grit tapered diamond bur (ISO #859-010, Komet, Engelskirchen, Germany) under air-water spray coolant to replicate depths similar to the NCCLs in the experimental teeth. The lesions and the prepared cavities were gently cleaned using a slurry of pumice and water on a slowly rotating rubber cup in order to remove micro-organisms and debris that may have contaminated the site.

The teeth were randomly divided among the three products evaluated; two dentin adhesive systems and an RM-GIC, as detailed in Table 1. They were applied according to the manufacturers' instructions as follows: One Coat Bond: dentin was etched for 30 seconds with 15% phosphoric acid gel, rinsed for 20 seconds and air

Table 1: Materials, Components, Chemical Composition, Batch Numbers and Manufacturers

Materials	Components	Chemical Composition	Batch #	Manufacturer
One Coat Bond	Etchant	Water, 15% phosphoric acid, gel former	HB 938	Coltène AG, Altstätten, Switzerland
	Priming resin	HEMA, UDMA, hydroxypropylmethacrylate, glycerol dimethacrylate, polyalkenoate methacrylized, amorphous silicic acid, 5% water	HB938	
Clearfil SE Bond	Self-etching primer	MDP, HEMA, hydrophilic dimethacrylate, dl-camphorquinone, N, N-diethanol-p-toluidine, water	150A	Kuraray, Osaka, Japan
	Adhesive resin	MDP, BIS-GMA, HEMA, hydrophobic dimethacrylate, dl-camphorquinone, N, N-diethanol-p-toluidine, silanated colloidal silica	32A	
Fuji II LC Capsule		Fluoroaluminium silicate glass, polyacrylic acid, HEMA	2091	GC International, Tokyo, Japan
Dentin Conditioner		10% polyacrylic acid	290571	GC

HEMA = hydroxyethyl methacrylate; UDMA = urethane dimethacrylate; MDP = 10-methacryloyloxydecyl dihydrogen phosphate; BIS-GMA = Bisphenol glycidyl methacrylate.

dried gently. Priming resin was massaged on the etched dentin for 20 seconds, gently air dried and light cured for 30 seconds. Clearfil SE Bond: Self-etching primer was applied on the dentin for 20 seconds and gently air dried. Adhesive resin was applied, air thinned and light cured for 10 seconds. Fuji II LC: Dentin was conditioned with Dentin Conditioner for 20 seconds, rinsed for 20 seconds, gently air dried, Fuji II LC applied and light cured for 20 seconds. For the resin-bonded specimens, the cavities were restored with a bulk placement of resin composite (Silux Plus, 3M Dental Products, St Paul, MN 55144, USA) and light cured for 40 seconds. All specimens were stored in tap water at 37°C for 24 hours, sectioned longitudinally through the lesion using a slow-speed diamond saw under copious water coolant and fixed in 10% phosphate buffered formalin for 24 hours. The resin-bonded specimens were polished with increasingly fine diamond pastes (6, 3, 1, 0.25 µm; Buehler, Lake Bluff, IL 60064, USA), air-dried, gold sputter-coated and observed using Field Emission-Scanning Electron Microscopy (FE-SEM) (XL30FEG; Philips, Eindhoven, The Netherlands). To determine the acid resistance of the hybrid layer, specimens were polished to remove the gold coating and immersed in 10% orthophosphoric acid for three-to-five seconds (Gwinnett & Kanca, 1992; Sano & others, 1995), rinsed in running water for 60 seconds, air-dried, re-coated with gold and observed with FE-SEM. After this, the specimens were polished, immersed in 10% orthophosphoric acid for three-to-five seconds, 5% NaOCl for 10 minutes (Wang & Nakabayashi, 1991), rinsed in running water, air-dried, gold sputter-coated and observed using FE-SEM.

The resin-modified GIC specimens were polished in the same manner as the resin-bonded specimens, immersed in 10% orthophosphoric acid for three-to-five seconds, 5% NaOCl for 10 minutes, rinsed in running water, air-dried, gold sputter-coated and observed using FE-SEM.

The thickness of the hybrid layer was measured from the micrographs; three measurements were performed on each specimen. No statistical analysis was performed due to the limited number of the specimens and because this study was designed to be qualitative.

RESULTS

The resin-dentin interfaces of the two adhesive systems and an RM-GIC are illustrated in the scanning electron micrographs shown in Figures 1-3. The hybrid layer was not clearly apparent in the polished specimens. After acid treatment, the hybrid layer was more distinct. When subjected to the acid and hypochlorite treatment, the thickness of the hybrid layer was slightly less than before such treatment in all groups.

The normal dentin bonded with One Coat Bond showed a hybrid layer ranging from 0.6-1 µm thick after acid treatment (Figure 1a) and approximately 0.4-0.6 µm after acid-hypochlorite treatment (Figure 1b). Resin penetration into dentinal tubules and lateral branches of tubules was clearly observed in all normal dentin specimens. The thickness of the hybrid layer in the NCCL specimens after acid treatment was about 0.6-0.7 µm (Figure 1c) and approximately 0.3-0.4 µm after acid-

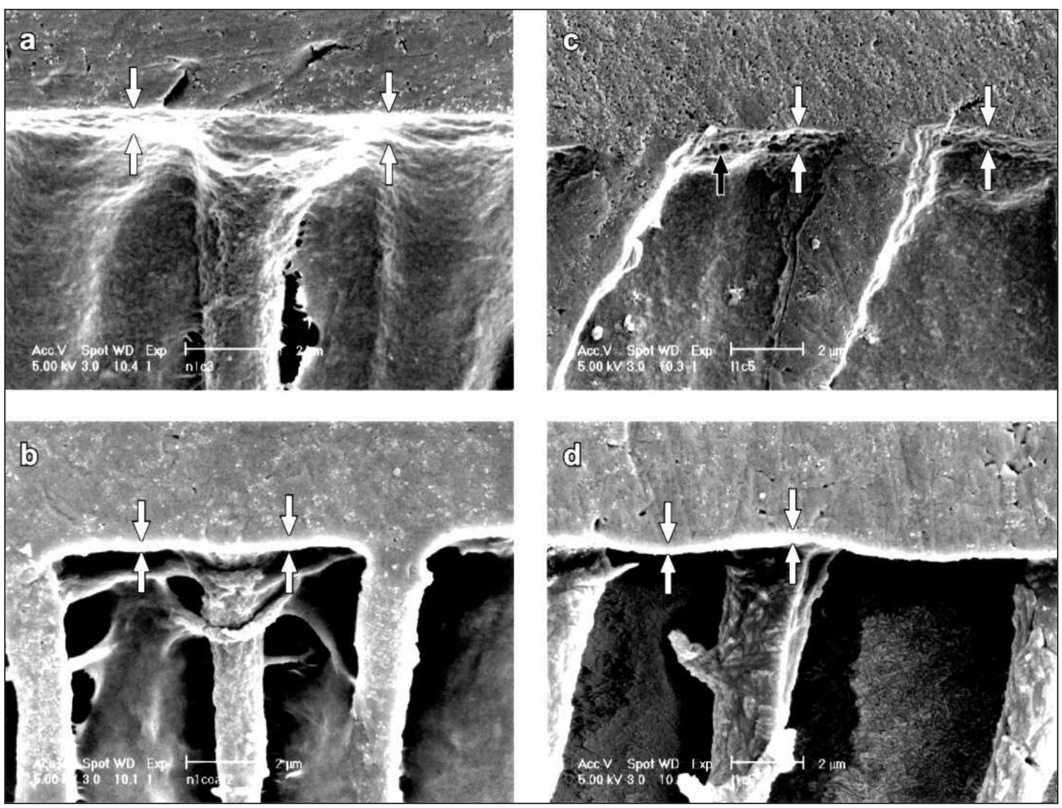

Figure 1. *SEM micrograph of resin-dentin interface created by One Coat Bond. a) normal dentin specimen after acid treatment, a hybrid layer about 0.6-1 µm thick can be observed (arrows). b) after acid-hypochlorite treatment, the hybrid layer approximately 0.4-0.6 µm thick (arrows) and resin tags with lateral branches are observed. c) NCCL specimen after acid treatment, the hybrid layer about 0.6-0.7 µm thick (white arrows) with some porosity (black arrows) is observed. d) after acid-hypochlorite treatment, a hybrid layer about 0.3-0.4 µm thick (arrows) and resin tags with short lateral branches can be observed.*

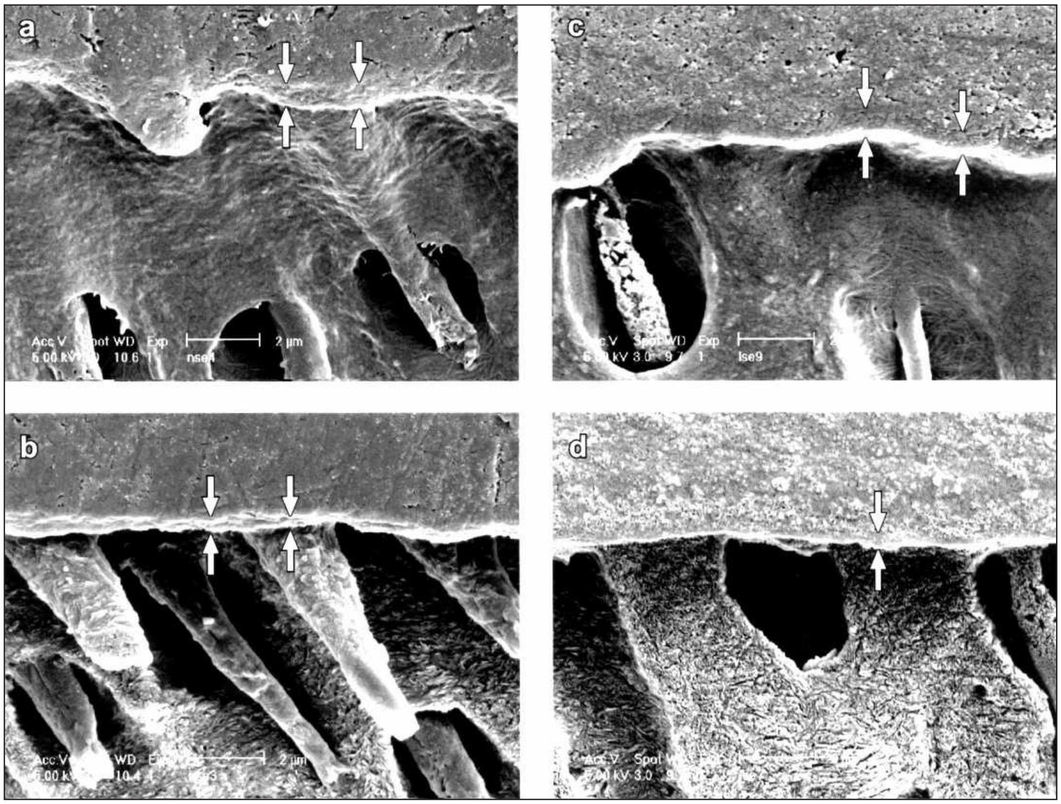

Figure 2. *SEM micrograph of resin-dentin interface created by Clearfil SE Bond. a) normal dentin specimen after acid treatment, a hybrid layer about 0.6-0.7 µm thick can be observed (arrows). b) after acid-hypochlorite treatment, a hybrid layer approximately 0.4-0.6 µm thick (arrows) with numerous resin tags can be observed. c) NCCL specimen after acid treatment, a hybrid layer about 0.4-0.6 µm thick (arrows) with poorly formed resin tag is observed. d) after acid-hypochlorite treatment, the hybrid layer about 0.3 µm thick (arrows) with very few resin tag is exhibited.*

hypochlorite treatment (Figure 1d). In the NCCL specimens, some porosity was observed within resin tags with limited resin penetration into lateral branches of dentinal tubules.

For Clearfil SE Bond, the hybrid layer thickness was about 0.6-0.7 µm in normal dentin after acid treatment (Figure 2a) and 0.4-0.6 µm after acid-hypochlorite treatment (Figure 2b). Resin tags were clearly evident, however, no resin penetration into the lateral branches was observed. For NCCL specimens, the hybrid layer thickness after acid treatment ranged between 0.4-0.6 µm (Figure 2c) and was approximately 0.3 µm after acid-hypochlorite treatment (Figure 2d). Very few resin tags were observed to have formed in the NCCL specimens. In the cases where tags were present, they were thin and poorly formed (not illustrated).

All RM-GIC specimens showed intimate adaptation to the underlying dentin and a cement matrix-dentin inter-diffusion zone. This zone was resistant to the acid-base treatment and was approximately 1.5-2 µm thick in normal dentin specimens (Figure 3a) and about 0.2-0.7 µm thick in dentin from NCCLs (Figure 3b). In some normal dentin specimens, penetration of the cement matrix into the dentinal tubules was also observed (not illustrated). No such penetration was observed in NCCL specimens.

DISCUSSION

To achieve good dentin adhesion with resin-based dentin bonding agents, it is necessary to prepare the dentin surface in such a way that facilitates the penetration of resin monomers. This is usually achieved by acid etching in order to remove the smear layer and demineralize the superficial dentin. For the recent etching-priming adhesive systems, acidic primers dissolve or modify the smear layer and produce mild demineralization of the underlying dentin (Watanabe, Nakabayashi & Pashley, 1994). Unlike sound dentin, the dentin surfaces of NCCLs lack a smear layer and are highly mineralized with occluded tubular openings that may reduce the effect of acid etching or acidic priming (Mixson & others, 1995; Sakoolnamarka & others, 2000). This may result in less reliable bonding of adhesive resins to such surfaces, as has been reported previously (Duke & Lindemuth, 1991; Gwinnett & Kanca, 1992; Van Meerbeek & others, 1994).

One Coat Bond has a primer-adhesive that is applied after 15% phosphoric acid etching. The hybrid layer created by this system to the surface of NCCLs appeared to be thinner than that of normal dentin and had resin tags with short lateral branches. This was presumably due to the high mineral content of the lesion surface that resulted in less demineralization of the surface for a given etching regimen (Perdigão & others, 1994; Sakoolnamarka & others, 2000). This may be a potential obstacle preventing resin infiltration into the demineralized NCCL surface. The hybrid layer thickness created by One Coat Bond to normal dentin in this study appeared to be thinner than that reported previously (Tanumiharja & others, 2000). This may be due to the difference in specimen selection. Bonding was performed on teeth from older patients extracted due to periodontal disease. Prati & others (1999) reported that a thinner hybrid layer was formed in old teeth compared with young teeth. This was presumably due to the inability of the acid to uniformly demineralize the old dentin. The increase of the inorganic component due to the aging process may also influence the hybrid layer thickness (Sidhu, Soh & Henderson, 1991). However, dentin age is believed to not show any great influence on bond strength (Burrow & others, 1994; Tagami & others, 1993).

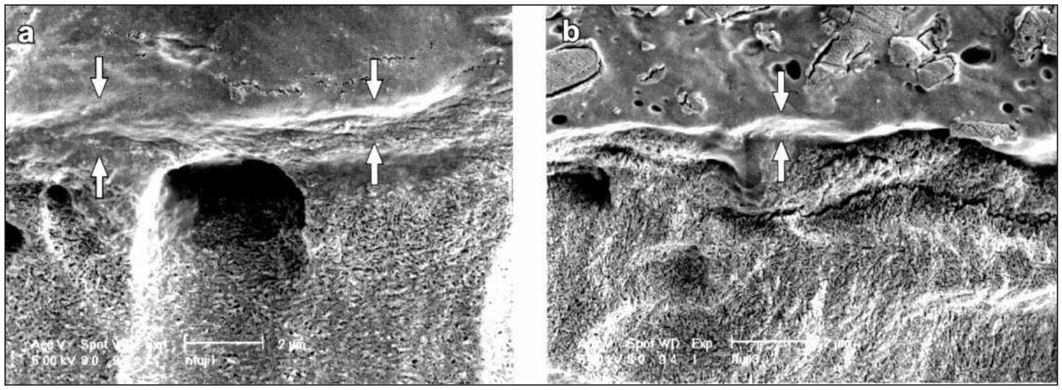

Figure 3. *SEM micrograph of Fuji II LC bonded specimen after acid-hypochlorite treatment. a) normal dentin: intimate adaptation to the underlying dentin and the cement matrix-dentin interdiffusion zone approximately 1.5-2 µm thick is exhibited (arrows). b) NCCL: the cement matrix-dentin inter-diffusion zone about 0.2-0.7 µm thick can be observed (arrows).*

The hybrid layer thickness created with Clearfil SE Bond to the dentin of NCCLs was very thin with few resin tags. This could be due to the self-etching primer being unable to sufficiently demineralize the surface of NCCLs that obstructs resin infiltration into dentin. In Clearfil SE Bond, which uses a weak acid, the difference between the dentin of NCCLs and normal dentin may be great enough to alter the ability to obtain strong bonds. Ferrari & others (1996) reported that after prolonged application (from 30 seconds to 60 seconds) of self-etching primer of Liner Bond 2 (Kuraray, Osaka, Japan), a similar material, the smear layer, was more likely to dissolve completely and a more uniform hybrid layer was observed. This etching time is longer than that specified by the manufacturer (30 seconds) but may improve adhesion of self-etching priming materials to dentin of NCCLs.

When the hybrid layers of normal dentin and NCCLs were compared for the two dentin adhesive systems, some variation in thickness and resin tag formation were observed. However, this cannot be used to indicate the quality of adhesion since previous studies (Phrukkanon & others, 2000; Prati & others, 1998; Yoshiyama & others, 1996) have reported that there was no correlation between the hybrid layer thickness and bond strength. The quality of the hybrid layer may be more important with respect to bond durability. After acid and hypochlorite treatment, the hybrid layers appeared to have been partially dissolved in NaOCl. This may be a consequence of the failure of resin monomers to penetrate to the base of the demineralized dentin, or the incomplete formation of poly-HEMA, leaving a porous region within the hybrid layer (Burrow & others, 1996; Phrukkanon & others, 2000) that may deteriorate and serve as a location for future failure. This is now thought to be an artifact.

The bonding of RM-GICs involves two mechanisms—chemical adhesion and micromechanical bonding (Lin, McIntyre & Davidson, 1992). It is believed that the adhesion of conventional GICs is the result of an ion-exchange mechanism by polyacrylate ions replacing phosphate ions of hydroxyapatite (Mount, 1994). For Fuji II LC, after using 10% polyacrylic acid to condition the dentin surface, the cement matrix (containing HEMA) penetrates the conditioned dentin and creates a micromechanical bond (Miyazaki & others, 1997). Previous studies reported no difference in adhesion to dentin when 10% polyacrylic acid (Dentin Conditioner; GC International, Tokyo, Japan) or 20% polyacrylic acid/3% aluminum chloride (Cavity Conditioner; GC International, Tokyo, Japan) was applied prior to applying GIC (Miyazaki & others, 1997; Pereira & others, 1997; Tanumiharja & others, 2001). Specimens were not examined at the "polished only" stage because the dessication process would have damaged the GIC, thus preventing further imaging. In this study, an acid-base resistant (ABR) layer (Tanumiharja & others, 2001) was observed between the RM-GIC and the underlying dentin. Tanumiharja & others (2001) proposed that the ABR layer may be a combination of an ion exchange layer and a hybrid-like layer since a hybridization process may occur due to the presence of resin in the RM-GIC. The thickness of the ABR layer was greater in normal dentin than in the dentin of NCCLs, and further study is needed to determine if this affects the stability of the bond. The interface between Fuji II LC and dentin showed penetration of the cement into the tubules of normal dentin (tag formation), which is consistent with the findings of previous studies (Pereira & others, 1997; Tanumiharja & others, 2001). The acids on which GICs are based are relatively mild due to their polymeric nature, and their long chains may reduce their ability to diffuse through dentinal tubules (Mount, 1995), although tags may be formed by the resin part of the material (Kato, Tosaki & Hirota, 1995).

Clinical studies have shown good clinical performance of RM-GICs bonded to dentin of NCCLs (Abdalla &

Alhadainy, 1997; Maneenut & Tyas, 1995; Neo & others, 1996). Whereas a clinical comparison of retention rate using adhesive resin and RM-GIC showed a lower retention rate of the former after three years (Horsted-Bindslev, Knudsen & Baelum, 1996; van Dijken, 2000), a decrease in color match and an increase in surface roughness were found for RM-GIC.

It is known that preparing biological specimens for SEM observation may generate artifactual changes (Carvalho & others, 1996). Since one requirement for the SEM to function properly is a dry, high-vacuum environment, dentin or any other hydrated material will dehydrate and may crack under such conditions (Ngo, Mount & Peters, 1997). The RM-GIC-bonded specimens could not be examined in the same manner as the adhesive resin bonded specimens, which required re-polishing and re-coating. Because RM-GIC is a water-based material, it dehydrates and cracks markedly under the high SEM vacuum (Ngo & others, 1997). Therefore, the repeated dehydration, rehydration and polishing as performed for the rein specimens was not considered feasible for Fuji II LC.

CONCLUSIONS

Within the limitations of the relatively small sample size, the dentin adhesive systems and the RM-GIC showed intimate adaptation to both normal dentin and the surface of the NCCLs. The hypothesis that there was no difference in the ultrastructure of the hybrid layer of normal dentin and NCCLs could not be supported. Furthermore, after NaOCl treatment, the hybrid layer thickness was less, which implied that a layer of collagen fibers was exposed and not fully enveloped by resin under the hybrid layer. Therefore, the hypothesis that there was no difference in the hybrid layer after NaOCl treatment was also not supported. Resin-modified GIC created a hybrid-like layer that was resistant to the acid-hypochlorite treatment. This layer was thicker in normal dentin than in NCCLs.

Clinical studies are necessary to determine the efficacy and long-term performance of One Coat Bond and Clearfil SE Bond bonded to the dentin of NCCLs.

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Marginal and Internal Adaptation of Stratified Compomer-Composite Class II Restorations

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I Krejci • C Davidson

Clinical Relevance

Placing a lining of compomer underneath direct Class II composite restorations may improve marginal and internal adaptation.

SUMMARY

Different approaches have been proposed to improve the adaptation of Class II restorations, including applying low-elasticity modulus base-liners. This *in vitro* fatigue test (or study) evaluated the influence of the compomer base-lining configuration on restoration adaptation. Direct Class II MOD box-shaped composite restorations with or without base and lining (n=3x8) were placed on intact human third molars with proximal margins 1 mm above or under the CEJ. The compomer (Dyract) was applied as a 1 mm-thick lining or as a base, closing proximo-gingival margins. Marginal adaptation was assessed before and after each phase of mechanical loading (250,000 cycles at 50N, 250,000 cycles at 75N and 500,000 cycles at 100N); internal adaptation was evaluated after test completion. Gold-sputtered resin replicas were observed in the SEM and restoration quality evaluated in percentages of continuity (C) at the margins and within the internal interface after sample section. Mechanical loading did not influence adaptation to enamel, while it adversely affected restoration adaptation to dentin for the full composite and compomer-base restorations (C varied, respectively, from 95.2 to 75.3% and from 98.0 to 10.6%). The internal adaptation quality showed the same general trend, however, with reduced scores of continuity. In this experimental condition, application of a low elasticity modulus layer under the restorative material proved advantageous but the compomer should not contact the gingival margins.

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INTRODUCTION

The polymerization shrinkage of resin composites has been reduced but not yet suppressed in commercially available brands (Feilzer, de Gee & Davidson, 1988; de Gee, Feilzer & Davidson, 1993; Stavridakis, Kakaboura & Krejci, 2000). Consequently, stresses induced by polymerization and their potentially damaging effect on restoration adaptation (Davidson, de Gee & Feilzer, 1984) still restrain a simple and safe application of direct techniques in large and deep Class II cavities. So far, most clinicians have addressed this problem by placing indirect restorations (Shortall & others 1989; Krejci & others 1990a; Dietschi & Spreafico, 1997). However, this option has obvious technical and socio-economic shortcomings. Improvements are therefore expected regarding the efficiency of bonding agents and the capacity of direct restorative methods to counteract and limit polymerization shrinkage stresses.

The first attempt to reduce polymerization shrinkage stress in Class II restorations was to apply the composite in several horizontal layers (Lutz & Kull, 1980). This concept was further developed and implemented by incorporating a glass ionomer base to reduce the amount of composite to be cured *in situ*, as well, as applying a more sophisticated layering method (Lutz & others, 1986a; Lutz, Krejci & Oldenburg, 1986b). Many alternative layering methods were still described, which help to control polymerization shrinkage vectors and related stresses (Weaver, Blank & Pelleu, 1988; Bertolotti, 1991; Tjan, Bergh & Lidner, 1992). Actually, this reduction in overall stress development is mainly achieved by maximizing the free surface (optimal configuration factor) which allows deformation to occur during setting without stress (flow) (Davidson & de Gee, 1984; Lutz & others, 1986a,b; Feilzer, de Gee & Davidson, 1987). However, currently, none of these incremental methods allow for a direct composite restoration to be placed without residual stresses in the material, tooth substance and adhesive interface. These internal tensions, together with functional forces, have the potential to produce adhesive or even cohesive failures (Dietschi & Krejci, 2001).

Reducing polymerization shrinkage and improving many physical properties of composites to be used in posterior teeth was achieved through increasing filler content (Willems & others, 1993). The potentially negative consequence of elevating most composite physical properties, including the elasticity modulus, is a reduction in their ability to flow and increase the stresses generated at the adhesive interface during polymerization (Feilzer, 1989; Feilzer, de Gee & Davidson, 1990). Therefore, Kemp-Scholte & Davidson (1990) early on emphasized the importance of incorporating an “elastic” layer at the restoration base to act as a stress absorber, then to reduce internal tensions induced by polymerization of further composite layers or function. This role can be assumed by the hybrid layer (Van Meerbeck & others, 1993), the bonding resin (Kemp-Scholte & Davidson 1990; Eliades, 1994) or a soft base-liner (Davidson, 1994; Roulet & Lösche, 1994; Friedl & others, 1997). Actually, the resin-modified glass ionomers and compomers can be combined to resin composites to form a resistant but less rigid base that could preserve adhesion due to a lower and slower development of polymerization stresses (Wilson, 1990; Friedl & others, 1997; Suh, 1997). For some brands, this interesting property seems related to a specific resinous matrix composition and structural network that shows little cross-linkage after light-activation, thus, providing higher initial material elasticity (Suh, 1997). The material, however, attains later superior mechanical strength after progression of the acid-base reaction and the development of an ionic substructure (Wilson, 1990).

The bond strength to dentin of resin-modified glass ionomers and composites proved comparable (Triana & others, 1994; van der Vyver, Jansen van Rensburg & de Wet, 1995; Fritz, Finger & Uno, 1996) because they rely on modern adhesive concepts through forming a hybrid layer. Since an effective bond can be achieved between resin-modified glass-ionomers and composites (Tate, Friedl & Powers, 1996; Friedl & others, 1997), the concept of stratified compomer-composite adhesive restorations appears to be a feasible and advantageous restorative option. However, in which configuration is the best restoration quality still needs to be determined

This study tested the hypothesis that the marginal and internal adaptation of direct Class II restorations after mechanical loading could by influenced by the presence and configuration of a low elasticity modulus compomer base.

METHODS AND MATERIALS

Sample Preparation

Freshly-extracted human third molars were used for this study. The inclusion criteria included the teeth needed to be free of decay and presented a complete apexification. The teeth were kept in an isotonic solution enriched with sodium azide (0.2%) at 4°C until the experiment started to prevent bacteria or fungus growth in the storage medium.

For each specimen, the root length was adjusted to fit in the test chamber of the mechanical loading device (Department of Cariology & Endodontology; Laboratory of Electronics of the Faculty of Medicine, University of Geneva). After the specimen was properly positioned, it was fixed with light-curing composite on a metallic holder and the root base was embedded with self-curing acrylic resin to complete the tooth stabilization. Box-shaped Class II cavities (MOD) with parallel walls and bevelled enamel margins were prepared, with proximal margins located 1.0 mm below (mesially) and above (distally) the cementum-enamel junction (Figure 1). The dimensions of the preparation were 4.0 mm in width and 2 mm in depth at the bottom of the proximal box and 2 x 4 mm (depth x width) in the occlusal area. The cavities were prepared using coarse diamond burs under profuse water spray (Geneva Prep Set; Intensiv; Viganello, CH 6962, Switzerland) and finished with fine grained burs of the same shape (Geneva Prep Set).

The 24 prepared teeth were randomly assigned to one of three experimental groups corresponding to the different restorative options: direct composite filling (CP), direct composite filling with a compomer lining (closed

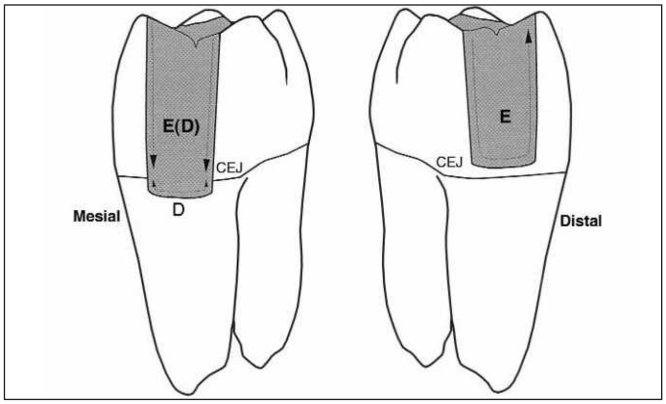

Figure 1. *Configuration of the Class II preparation used in this study, showing the different areas considered for the marginal adaptation evaluation.*

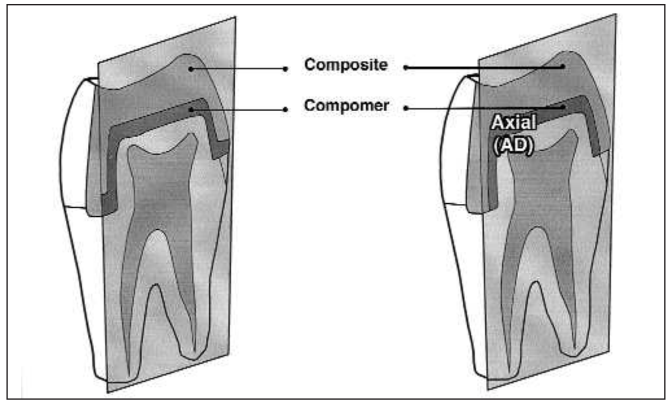

Figure 2. *Diagrammatic representation of the LD (compomer lining) and BD (compomer base) groups (left) and the CP (compomer lining) group (right.)*

Table 1: *Composition and Elasticity Module of the Products Under Investigation (manufacturer's data)*

Materials	Product Name	Composition (Manufacturer)	Elasticity Module	Batch #s
tissue conditioner	UltraEtch, (Ultradent; South Jordan, UT 84095, USA)	H_3PO_4 37% Gel	- -	- -
adhesive	Prime & Bond 2.1 (Dentsply DeTrey; Kontsanz, Germany)	Dymethacrylate resins, PENTA, monophotoinitiators, stabilizers, cetylamine hydrofluoride, acetone acetone	1. 60 Gpa* 1.20 GPa**	960820
base-liner	Dyract (Dentsply DeTrey; Kontsanz, Germany	UDMA resin, TCB resin Strontium fluoro-silicate glass, strontium fluoride glass Initiators, stabilizers	7.4 GPa* 6.1 GPa***	961016
restorative material	TPH spectrum (Dentsply DeTrey; Kontsanz, Germany	mod BISGMA, BISEMA, TEGDMA barium alumino boro silicate glass, colloidal silica Initiators, stabilizers	10.6 GPa*	961016
dentin			12 GPa+	
enamel			50 GPa+	

** measured at 24 hours, ** measured at 30 days, ***measured at 90 days, + Verluis & others, 1996*

"sandwich" configuration) (LD) and direct composite filling with a compomer base (opened "sandwich" configuration, with base material covering gingival margins) (BD) (Figure 2).

Restorative Procedures

The same restorative composite material, a fine hybrid brand (TPH Spectrum, Dentsply DeTrey; Kontsanz, D-78467, Germany) and the same multi-functional adhesive (Prime & Bond 2.1, Dentsply DeTrey) were used in all groups. Table 1 summarizes the characteristics of these materials.

After completing the preparation, enamel was selectively etched for 30 seconds prior to a 15-second full cavity etching with a 37% H_3PO_4 acid gel (UltraEtch; Ultradent; South Jordan, UT 84095, USA). The cavity was thoroughly rinsed for 30 seconds and gently air dried (three seconds air spray with low pressure) so that conditioned dentin was kept slightly moist. Then, the adhesive was placed in two layers according to manufacturer's instructions and light-cured for 40 seconds. For the full composite fillings (group CP), the three-sited light curing technique (Lutz & others, 1986a,b) and the oblique layering technique (Weaver & others, 1988; Tjan & others, 1992) were used to respectively restore the proximal and occlusal portions. Each increment was individually cured from gingivally (first layer) and laterally (all subsequent layers) for 40 seconds, with a final 40 seconds occlusal illumination, using a halogen light-curing unit (Optilux 500, Kerr-Demetron; Orange, CA 92867, USA), the power density of which is about 500 mW/cm^2. The compomer lining (Dyract, Dentsply DeTrey) (Group LD) was applied uniformly (1.5 mm thickness approximately) on the bottom

Table 2: *Summary of Restorative Procedures*

Groups	Restorative Materials Applied	Restorative Procedures	Closure at Gingival Margins by
CP	adhesive composite	prox: 3 site-layering * occl: oblique layering	adhesive/composite
LD	adhesive compomer composite	prox: 3 site-layering * occl: oblique layering	adhesive/composite
BD	adhesive compomer composite	prox: 2 site-layering ** occl: oblique layering	adhesive/compomer

** Lutz & others, 1986a,b*
*** only layers 2 and 3 of the the 3-sited-ligth curing technique*

of the cavity (Figure 2), maintaining the gingival margins free for composite application. The compomer base (Dyract, Dentsply DeTrey) (Group BD) was applied uniformly over the proximal boxes and the occlusal preparation ground (1.5 mm thickness approximately) (Figure 2). Compomer lining and base were light cured for 40 seconds using the same halogen curing device. The remaining volume of both based and lined cavities was filled similarly to those of Group CP, with the exception of the first gingival layer that was not applied in samples with a base (Group BD). Finally, each restoration was covered with a glycerine gel and light cured for a final 20 seconds irradiation on each surface. Flame and pear-shape fine diamonds burs (Intensiv No 4205L; 4255; 5205L and 5255) and polishing discs (Pop-On XT, 3M, St Paul, MN 55144, USA) were used for immediate restoration finishing and polishing.

Restorative procedures are summarized in Table 2.

Mechanical Loading

The stress test was carried out after a 24-hour delay. The pulpal chamber was penetrated buccally or lingually with a tube (sealed with DBA) that was connected to a simulated pulpal circuit of saline water under a pressure of 14 cm H_20 (Ciucchi & others, 1995). All specimens were successively submitted to 250,000 cycles with 50N loading force, 250,000 with 75N and 500,000 cycles with 100N, representing a total of 1,000,000 loading cycles. The axial force was exerted at a 1.5 Hz frequency following a one-half sine wave curve. These conditions are believed to simulate about four years of clinical service (Krejci & others, 1990a; Krejci, Picco & Lutz, 1990b; Krejci, Heinzmann & Lutz, 1990c). The restored teeth were contacted by antagonist artificial cusps made of stainless steel, the hardness of which is similar to natural enamel (Vickers hardnesses: enamel = 320-325; steel = 315). The diameter of the cusps was 4 mm and they were placed 1 mm above the restoration occlusal surface, about 1.5 mm out of the central fossa. The specimen was mounted on a rubber disc, with a sliding movement of the restored tooth made possible between the first contact on the inclined plane and the central fossa. The functions of this experimental device are similar to the machine developed by Krejci & others. (1990b).

Specimen Evaluation

Prior to the fatigue test and after completing each loading phase, the restoration margins were cleaned with a brush and fine pumice and acid-etched with 37% H_3PO_4 gel (30 seconds on enamel and 10 seconds on dentin). Then, gold sputtered epoxy resin replicas (Epofix, Struers; Rødrove, DK-2610, Denmark) were made from polyvinylsiloxane impressions (President light and heavy body, Coltène AG, Alstätten, CH 9450, Switzerland). The proximal tooth-restoration interface was analyzed quantitatively with the scanning electron microscopy (SEM) (Digital SEM XL20, Philips, Eindhoven, 5600 MD, Netherlands) by employing a recognized evaluation method (Luescher & others, 1977; Roulet, 1986). The following evaluation criteria were applied: continuity, overfilling, underfilling, marginal opening, marginal restoration or tooth fracture. The restoration margins were observed at a standard 150x magnification. When necessary for assessment accuracy, higher magnifications were used. Results for the restoration marginal adaptation prior to and following the different loading phases are expressed as percentages of margins in "continuity" for the three segments under evaluation—enamel margins on the distal tooth side (E), and enamel (ED) and dentin (D) margins on the mesial tooth side (Figure 1). The restoration occlusal adaptation was not assessed.

Upon completion of the mechanical loading, the teeth were embedded in a slow self-curing epoxy resin (Epofix) and sectioned mesio-distally into three parts with a central slice of 1 mm, using a slow rotating saw (Isomet 11-1180, Buehlers, Lake Bluff, IL 60044, USA). The sections were successively polished with 200, 400 and 600 grit SiC paper and etched for one minute with a 37% H_3PO_4 gel. Impressions were then taken from the four available surfaces for fabricating gold sputtered resin replicas. To avoid observation artifacts, special care was taken not to dehydrate the prior samples by taking the impression with a "moisture tolerant" material (President light body) (Coltene AG). The restoration internal adaptation was assessed quantitatively on the gold-sputtered replicas under the SEM at a 150x magnification and it was judged according to two criteria: continuity and interfacial opening. Results

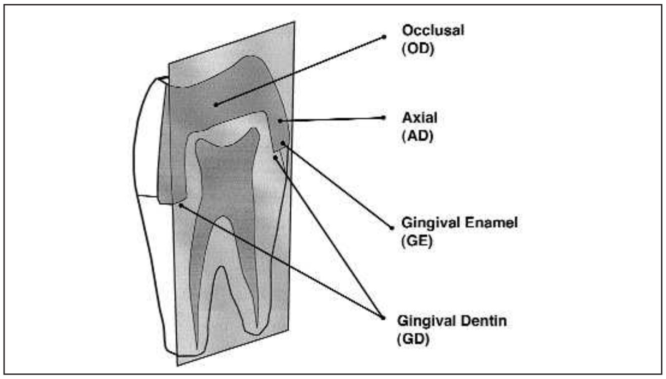

Figure 3. *Different areas considered for the internal adaptation evaluation.*

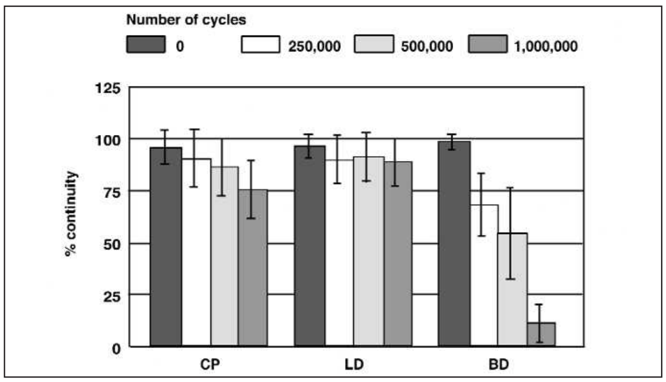

Figure 4. *Results of the marginal adaptation in dentin (% of continuity ±SD).*

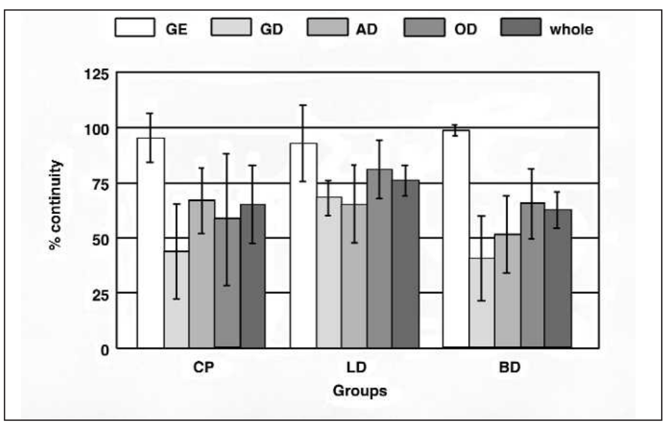

Figure 5. *Results of the internal adaptation in dentin (% of continuity ±SD).*

are expressed as the percentage of interface in "continuity" relative to the whole dentin interface (total) and to the following dentin segments: gingival enamel (GE), gingival dentin (GD), axial dentin (AD) and occlusal dentin (OD) (Figure 3). For each sample, results are expressed as a mean value, resulting from the evaluation of the four sections. The localization of bonding failures within the adhesive interface was tentatively identified, using higher magnifications (up to 1000x). A single trained evaluator performed all SEM observations.

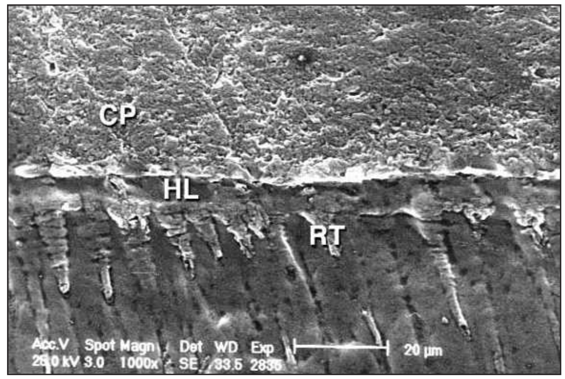

Figure 6. *SEM microphotograph of a CP sample section (composite filling) showing the adhesive interface with its different constituents, as revealed by the observation method: the resin tags (RT), the hybrid layer (HL and the bonding resin together form the composite restoration (CP).*

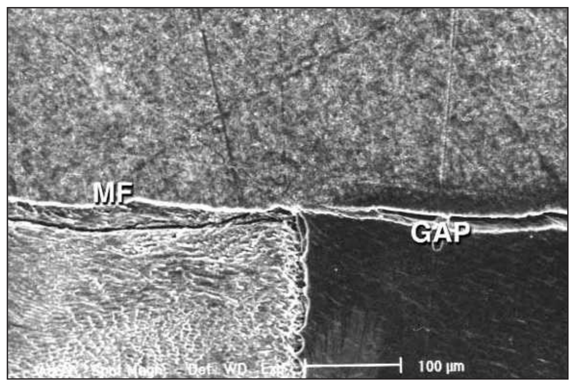

Figure 7. *SEM micrograph of a CP sample section (composite filling) demonstrating the two typical failure types: cohesive micro-fractures in superficial enamel (MF) and debonding on the top of the hybrid layer (GAP) in dentin.*

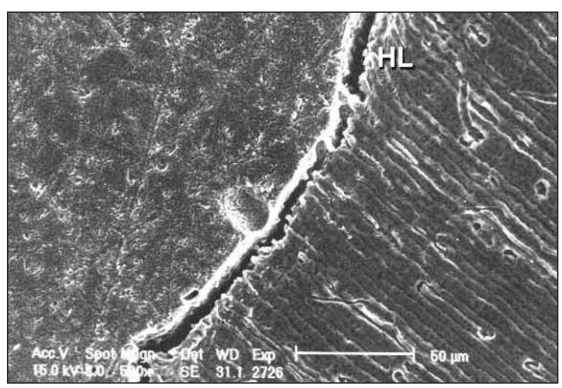

Figure 8. *SEM microphotograph of a CP sample section (composite filling) showing a rather rare type of failure: cohesive debonding within the hybrid layer (HL). In addition, cohesive dentin fractures were virtually absent in this study.*

All results were submitted to a non-parametric statistical analysis. The Kruskall Wallis and Nemenyi

Table 3: *Results of the Marginal Adaptation Evaluation at the Different Proximal Locations According to the Number of Mechanical Loading Cycles (percentages of continuity +/- SD)*

# of cycles	Location	CP	LD	BD
0	Enamel (distal)	100 (-)	97.3 (5.6)	97.6 (6.7)
250,000		99.5 (1.4)	97.6 (6.7)	98.6 (3.8)
500,000		100 (-)	95.5 (7.0)	100 (-)
1,000,000		100 (-)	94.6 (5.6)	100 (-)
0	Enamel (mesial)	100 (-)	97.9 (3.4)	98.8 (3.1)
250,000		100 (-)	98.0 (3.8)	98.8 (3.1)
500,000		100 (-)	97.9 (3.8)	99.3 (1.7)
1,000,000		100 (-)	97.6 (4.2)	99.3 (1.7)
0	Dentin	95.2 (8.9) a, A	96.3 (5.6) a, A, B	98.0 (3.3) a, A
250,000		90.3 (13.7) a, A, B	89.5 (11.8) a, b, C	67.5 (14.9) b, B
500,000		86.3 (13.7) a, A, B,C	90.7 (11.4) a, B, C	53.7 (21.7) b, B
1,000,000		75.3 (13.7) a, b, C	88.4 (11.6) a, C	10.6 (8.9) b, C

No significant difference was found for enamel margins. For comparison between groups (rows), means with same lower case letter are not statistically different at p*=0.05 using the Kruskall Wallis and Nemenyi tests. For comparison between the number of cycles (columns), means with same capital letter are not statistically different at* p*=0.05 using the Friedman and Wilcoxon-Wilcox tests.*

tests (Sachs, 1974) served to compare the restorative methods. The Friedman and Wilcoxon-Wilcox tests (Sachs, 1974) served to evaluate the influence of the number of cycles on the marginal adaptation. All tests were carried out at a 5% level of significance.

RESULTS

Marginal Adaptation

The results of the marginal adaptation are presented in Figure 4 and Table 3, together with the statistical analysis.

The proximal adaptation of the restorations in enamel proved satisfactory in the three groups for both mesial and distal sides, with percentages of "continuity" between 94.6% (LD) and 100% (BD) after one million cycles. The only type of defect observed at the enamel margins was the "marginal tooth fracture," which extent was usually strictly limited.

In dentin, the adaptation was judged excellent, with the proportions of "continuity" between 95.2% (CP) and 98.0% (BD) before mechanical loading. Loading produced a slight degradation of margins for the full composite restoration (CP) ("continuity" values varied from 90.3% to 75.3%, between 250,000 and one million cycles), while it remained stable for the restorations with the compomer lining (LD) ("continuity" values varied from 89.5% to 88.4% between 250,000 and one million cycles). The degradation at the dentin margins was severe for restorations with the compomer base (BD) ("continuity" values dropped from 67.5% to 10.6%, between 250,000 and one million cycles).

Internal Adaptation

The results of the internal adaptation evaluation are presented in Figure 5 and Table 4, together with the statistical analysis.

The evaluation of internal adhesive interfaces showed higher proportions of "continuity" at the gingival enamel (95.4% for CP to 98.4% for BD) when compared to dentin segments (40.4% for BD, gingivally, to 80.8% for LD, occlusally). The difference, however, proved significant only between the gingival dentin and gingival enamel portions. Applying a compomer lining allowed for a significant reduction in occurrence of gaps in dentin at the gingival level as compared to the base configuration or composite filling without base-lining.

Micromorphology of Internal Interfaces

In case of adhesive failure, the most common observation was that the separation was predominantly located at the top of an acid resistant layer, which seemingly corresponds to the "hybrid layer" (Figures 6 and 7). In enamel, failures appeared to be of a cohesive nature (Figure 7). The presumed hybrid layer generally appeared to be 5 to 10 µm thick. Only insignificant proportions of the defective interfaces showed evidence of another failure mechanism, such as cohesive fractures in dentin or within the hybrid layer (Figure 8). Adhesive failures resulting from a detachment at the hybrid layer base were, in fact, not detected.

DISCUSSION

Marginal Adaptation

The quality of the restoration marginal adaptation at the level of enamel margins remained nearly unaffected

Table 4: *Results of the Internal Adaptation Evaluation, According to the Different Interface Segments and the Whole Dentin Interface (total) (percentages of continuity +/-SD)*

Groups	GE	GD	AD	OD	Total
CP	95.4 a, A (11.1)	43.8 a, B (21.5)	66.5 a, A, B (15.0)	58.3 a, A, B (30.0)	64.8a (17.8)
LD	92.6 a, A (17.5)	68.1 b, B (7.9)	65.0 a, A, B (17.6)	80.8 a, A, B (13.2)	75.6a (6.8)
BD	98.4 a, A (2.2)	40.4 a, B (19.2)	51.2 a, A, B (17.4)	65.3 a, A, B (15.4)	62.5a (8.2)

For comparison between products (columns), means with same lower case letter are not statistically different at p=0.05 *using the Kruskall Wallis and Nemenyi tests. For comparison between locations (rows), means with same capital letter are not statistically different at* p=0.05 *using the Kruskall Wallis and Nemenyi tests.*

by the mechanical loading in all three groups. This again proves the superior efficiency and predictability of adhesion to acid-etched enamel and the value of beveling cavity margins (Munechika & others, 1984; Carvahlo & others, 2000). Actually, the incidence of marginal tooth fracture was negligible and without any significant difference among the different groups. Enamel micro-cracks seem typical of *in vitro* tests with mechanical loading when butt preparations are realized (Krejci, Lutz & Reimer, 1993; Dietschi & Moor, 1999), while such defects are significantly reduced with beveled preparations (Dietschi & Herzfeld, 1998). This observation likely reflects the influence of prism orientation in bonding efficiency to acid-etched enamel (Munechika & others, 1984; Carvalho & others, 2000). Therefore, beveling cavity margins appears to be the ideal finishing design for direct composite restorations in any area providing proper access and anatomy.

Unlike enamel margins, restoration adaptation to gingival dentin was significantly affected by mechanical loading for the full composite restorations and for those with a compomer base that presented almost fully opened margins at the end of the test. Applying a more elastic layer underneath an adhesive restoration proved to help absorb polymerization shrinkage and functional stresses (Kemp-Scholte & Davidson 1990; Van Meerbeck & others, 1993; Eliades, 1994). It remained to be determined, however, as to which base-lining configuration is best suitable. In the present experimental conditions, the restorations with a base (the compomer assumes the gingival closure of the cavity) behaved similarly to the other configurations prior to the fatigue test but proved inadequate to resist mechanical loading. This presumably reflects the influence of some specific physical properties of the tested material. The higher flexibility and more important volume of the base likely amplified deformations under simulated occlusal loading. In gingival dentin where the adhesion is the most critical, this resulted in an excessive proportion of opened margins. Krejci, Lutz & Krejci (1988) made similar observations after testing different base-liners under Class II restorations, although at this time, non-adhesive cements were used. A restorative material, such as a resin composite exhibiting physical properties, and, in particular, an elasticity modulus close to natural dentin, seems necessary to cover the margins and maintain the peripheral seal.

The best results were obtained with the lining configuration, suggesting that a rather thin layer of Dyract (1 mm) was adequate to reduce stress but did not result in excessive deformation under load. Actually, due to its low initial elasticity modulus (Suh, 1997), this specific material shows a good potential in this application.

In the three groups, the restoration adaptation to dentin appeared inferior to that of enamel. The numerous laboratory measurements of dentin bonding shear or tensile strength that present adhesion values identical, if not superior, to those obtained on acid-etched enamel (Hasegawa & others, 1995; May, Swift & Bayne, 1997; Wakefield & others, 1998; Wilder & others, 1998; Tanumiharja, Burrow & Tyas, 2000) are, in fact, poorly relevant for predicting their performance in a clinical configuration.

Internal Adaptation

Regarding the influence of the restorative technique and the superior efficiency of adhesion to enamel, the results of the internal and marginal adaptation proved to be in good correlation. The gingival portions presented more gaps than the axial or occlusal areas, although this appeared to be only a trend. Therefore, even in the absence of any statistical evidence, this observation substantiates the concept that the variation in tubule density and orientation within the different cavity areas can affect dentin-bonding efficiency (Watanabe, Marshall & Marshall, 1996; Ciucchi & others, 1996) (Figure 9). In superficial dentin, the surface occupied by tubules is minimal and, with the exception of the occlusal floor, their orientation is not perpendicular to the cavity base, thus reducing their contribution to dentin bonding and lowering the overall adhesion efficiency (Cagidiaco & Ferrari, 1995; Cagidiaco & others, 1997). Although it appears logical, this hypothesis remains controversial (Yoshiyama & others, 1996). The proportion of adhesive failures was higher internally than externally. This observation proves again that adhesion to dentin is perfectible and that marginal adaptation does not fully reflect the integrity of the internal adhesive interface.

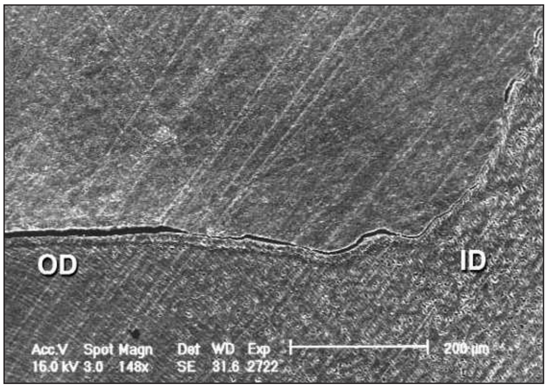

Figure 9. *SEM microphotograph of an LD sample (compomer lining showing a rather large gap close to the cavity margin that progressively closes toward the pulpal all. Note the inclination and reduced opening of tubules on the proximo-gingival border. (OD=superficial dentin; ID=inner dentin)*

Micromorphology of the Internal Adhesive Interface

The presence of an acid resistant layer on the top of dentin with clearly visible resin tags (Figures 6 and 7) was rather consistently observed underneath the restoration, which likely represents the hybrid layer. The absence of this layer at the restoration interface with enamel confirms this assumption. The morphological characteristics of the hybrid layer obtained with Prime & bond 2.1 appeared consistent with the observations made by Perdigão & others (1996) and Tay & others, (1996a,b). An indirect observation on replicas, such as applied in this study, precluded a precise distinction of all components of the adhesive interface but, whenever present, it allowed a localization of debonding relative to the hybrid layer.

The adhesive failures were predominantly located over the acid-resistant layer, which suggest a weak link between the hybrid layer top surface and the restoration. This observation confirms previous findings (Jacobsen & Finger, 1993; Dietschi, Magne & Holz, 1995; Perdigão & others, 1996). Tay & others (1996a,b) evidentiated the "over-wet" phenomenon related to the interaction between residual water and primer/adhesives containing acetone as the main solvent. Actually, by applying the concept of "wet-bonding" (Gwinnet, 1992; Kanca, 1992), the displaced water causes the formation of blister-like spaces and also inhomogeneous phases within the adhesive interface that could act as stress raisers on top of the hybrid layer. The problem of dealing with the excess water remains critical for some current adhesive systems. Actually, even when drying etched dentin moderately, there is a risk to affect the bond strength due to a collapse of the collagen structure and incomplete infiltration of the resinous components within the demineralized dentin (Pashley & others, 1993; Tay & others, 1996a,b). A last potential explanation for the existence of this weak link between the hybrid layer and restoration is an insufficient polymerization in the rather thin resin layer left after adhesive placement and solvent evaporation (only a few microns) (Van Merbeek & others, 1992; Van Meerbeeck & others, 1993; Prati & others, 1999). Actually, the inhibitory effect of oxygen is known to affect resin polymerization to a depth of 100 µm or more and to create a totally uncured layer of about 15 µm (Rueggeberg & Margeson, 1990). As a consequence, the collagen network might be disturbed during composite placement in the case that only a thin resin layer was produced over treated dentin. It is actually known that a stabilization of the hybrid layer by proper curing of the bonding resin is critical to optimize bond strength and marginal adaptation of indirect and direct Class II restorations (Frankenberger & others, 1999).

CONCLUSIONS

An *in vitro* fatigue test simulating four years of occlusal function was applied to direct full-composite and stratified compomer-composite Class II restorations in order to evaluate the influence of a compomer base or lining on marginal and internal adaptation. In these experimental conditions, it appeared that:

- mechanical loading had a detrimental effect on restoration adaptation to dentin while it did not influence adaptation to enamel. Although laboratory bond strength values of Prime & Bond 2.01 to dentin and enamel proved identical, this adhesive remains less effective on dentin than on acid-etched enamel when evaluated in a clinical configuration.
- the incidence of adhesive failures in dentin increased with the number of mechanical loading cycles. This reduction in the proportion of continuous margins appeared significant for the restorations with a Dyract base or no base-lining (full composite).
- the compomer Dyract applied as a base, extending up to the restoration margins, proved inadequate for preserving margin integrity in dentin, while it improved the restoration quality in the lining configuration. The use of a low elasticity modulus layer under the restorative material seems advantageous, providing its volume and configuration are well determined.
- adhesive failures occurred predominantly at the hybrid layer top surface.

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Guidance of Shrinkage Vectors vs Irradiation at Reduced Intensity for Improving Marginal Seal of Class V Resin-Based Composite Restorations *In Vitro*

N Hofmann • O Hiltl
B Hugo • B Klaiber

Clinical Relevance

Irradiation at 250 mW/cm² or at 600 mW/cm² administered from 10 mm distance may be adequate to photo-activate the hybrid resin composite evaluated in this study and better preserve marginal seal of Class V restorations compared to starting irradiation at the cervical margin.

SUMMARY

This study evaluated the influence of radiation intensity on polymerization of a resin-based composite (RBC) and compared the influence of guidance of shrinkage vectors vs irradiation at reduced light intensity on the marginal seal of Class V RBC restorations in vitro**.**

The degree of cure was studied indirectly by measuring the Vickers hardness (1.96 N, 30 seconds) at the bottom of disc-shaped specimens 2 mm in height at different periods of time after light irradiation. After one hour, irradiation using a high-intensity curing light (Heliolux GTE, Vivadent, 600 mW/cm²) [HICL] from close distance for 20 seconds, 40 seconds or 60 seconds or a low-intensity curing light (Vivalux, 250 mW/cm²) [LICL] from close distance for 60 seconds produced higher hardness values compared to 20 seconds or 40 seconds using the LICL or using the HICL from a distance of 10 mm. After three and 24 hours, higher hardness was observed for all irradiation protocols. After 24 hours, only specimens irradiated by the HICL for 20 seconds or 40 seconds from 10 mm distance featured significantly lower hardness compared to the remaining curing modes. The influence of different irradiation strategies on marginal seal of Class V RBC restorations was evaluated in vitro **using dye penetration after water storage (60 days, 37°C) and thermocycling (2500 cycles 5°-55°C). The HICL produced more dye penetration than the LICL. Placing the light tip directly over or 10 mm above the center of the cavity ("standard irradiation, ["distance irradiation"]") resulted in similar penetration values. In contrast, positioning the light tip apical to the cervical margin and moving it slowly to the center of the cavity ("cervical start irradiation") compromised the marginal seal.**

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INTRODUCTION

Despite considerable scientific effort, non-shrinking resins are still not available. Polymerization contraction may result in gap formation, marginal leakage and secondary caries. To overcome these side effects, various placement techniques and light curing procedures have been proposed. In this respect, two schools of thought can be distinguished.

The concept of guiding the direction of polymerization shrinkage towards the cavity margins is based on the assumption that the contraction of photo-activated resin-based composite is directed towards the light source. According to this hypothesis, placing the light source close to the cavity margin and irradiating the resin-based composite from this site will cause the composite to shrink towards the margin rather than away from it and reduce margin gap formation. To put this into practice, the three-sited light curing technique (Lutz, Krejci & Oldenburg, 1986) has been recommended. In the case of interproximal box-shaped posterior cavities, a cervical increment is placed and irradiated indirectly from a cervical direction using light reflecting wedges. The rest of the cavity is filled applying a buccal and lingual increment, both of which are light cured through the respective cavity walls.

However, the premise of shrinkage towards the light source has been challenged. Recent reports have provided a new interpretation of the underlying phenomena (Asmussen & Peutzfeldt, 1999; Suh & Wang, 2001). If a box-shaped cavity is filled with a rather thick layer of resin-based composite, most of the light is absorbed in the layer closest to the light source. In this case, the surface hardens and bonds to the margins, and the material shrinks toward the regions that cured first, that is, toward the light source. In contrast, if the composite layer is thin enough to let the light go straight through it, the material will cure instantaneously and shrink toward the underlying surface, especially if the surface is flat rather than box-shaped. Moreover, irradiating indirectly via light reflecting wedges or through dental hard tissues will considerably reduce the light intensity, and the benefits of the three-sited light curing technique may be attributed to this reduced light intensity rather than to the guidance of shrinkage vectors (Lösche, 1999).

The second concept for reducing margin gap formation is based on polymerization at reduced rate (Uno & Asmussen, 1991). Prior to gelation of the resin, shrinkage is compensated for by flow of the resin-based composite (Davidson & de Gee, 1984) and will not create as high stress at the tooth-restoration interface. When polymerization is performed or started at a reduced rate by irradiating at low intensity, for example, the pre-gel phase may be extended, a larger portion of the overall shrinkage may be compensated by flow and stress at the cavity margin might be reduced (Bouschlicher, Vargas & Boyer, 1997; Koran & Kürschner, 1998; Sakaguchi & Berge, 1998; Bouschlicher, Rueggeberg & Boyer, 2000; Bouschlicher & Rueggeberg, 2001). Consequently, these restorations may feature an improved marginal seal (Feilzer & others, 1995; Unterbrink & Muessner, 1995; Mehl, Hickel & Kunzelmann, 1997; Kanca & Suh, 1999; Yoshikawa, Burrow & Tagami, 2001a,b).

However, radiation intensity must not be reduced to the degree where complete polymerization is compromised because this would produce inferior mechanical properties, increase water sorption and content of residual monomer (Pearson & Longman, 1989) of the respective resin-based composites and compromise their biocompatibility (Caughman & others, 1991). These disadvantages would then outweigh the favorable marginal seal.

This investigation tested the hypothesis that photo-activated resin-based composite can be successfully cured at reduced light intensity while maintaining degree of cure. In addition, it evaluated the hypothesis that both curing at reduced intensity and irradiation from the cavity margin improve the marginal seal of Class V resin-based composite restorations. The variation of radiation intensity was created by using two different light curing units featuring different radiation output levels and by using these units in close contact to or at a distance of 10 mm from the irradiated objects. Polymerization of the resin-based composite specimens was evaluated by measuring their Vickers hardness. The marginal seal of the restorations was studied using dye penetration.

METHODS AND MATERIALS

For the first part of this study, cylindrical specimens of 2 mm height were fabricated between microscope slides using a fine hybrid resin-based composite (Tetric, Shade A2, Lot 613797, Vivadent, FL-9494 Schaan, Liechtenstein). The specimens were irradiated for 20 seconds, 40 seconds or 60 seconds using a low intensity (Vivalux, Vivadent, 250 mW/cm^2 as determined by the Curing Radiometer, Demetron, Danbury CT 06810, USA) or a high intensity halogen curing light (Heliolux GTE, Vivadent, 600 mW/cm^2). The light guide of the low-intensity light was placed directly on the microscope slide, whereas the high-intensity light was placed either directly on the microscope slide or at a distance of 10 mm from the slide. Used from 10 mm distance, the high-intensity light provided an intensity of 200 mW/cm^2 (Curing Radiometer). For every light curing protocol, six specimens were prepared and stored in the dark.

One, three and 24 hours after irradiation, the Vickers hardness was evaluated on the surface opposite to irradiation using a hardness tester (3212, Zwick, D-89079

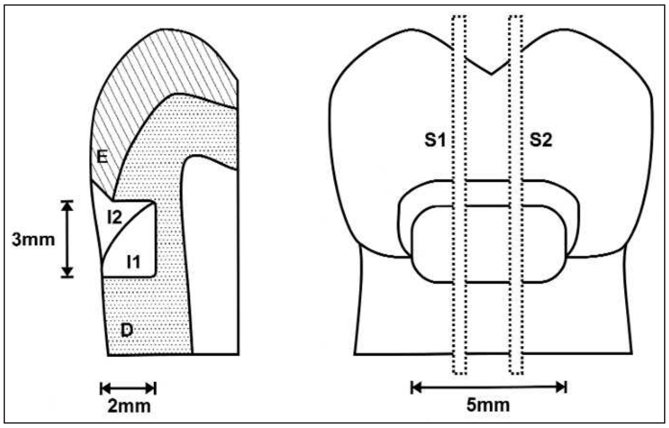

Figure 1. *Cross-section of the cavities showing the cavity dimensions and the configuration of the increments (left); buccal view of the cavities showing the location of the sections (S1/S2) made for the evaluation of dye penetration (right); D=dentin, E=enamel, I1/I2= first/second increment.*

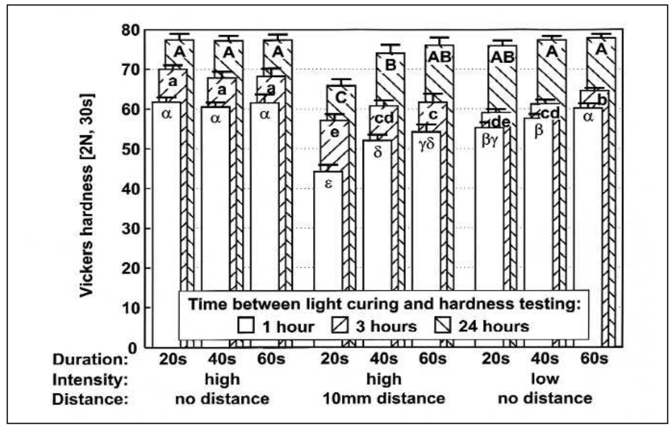

Figure 2. *Vickers hardness results [VHN 0.2/30] one, four and 24 hours after irradiation (mean ± standard deviation, n = 6); groups not different at a significance level of* p*<0.05 (Tukey's HSD) are indicated by identical letters with greek, lower and upper case letters specifying the different curing periods.*

Ulm, Germany) applying a load of 1.96 N (0.2 kp) for 30 seconds. Following the measurements after one hour, a layer of 100 µm was removed from the surface by wet grinding on silicon carbide paper of 800 grit. Between measurements after three and 24 hours, the specimens were stored at 37°C. After each storage period, the hardness measurements were replicated six times on each specimen with the results being averaged. For each storage period the differences between the experimental groups were tested for statistical significance using one-way ANOVA. Homogeneous subgroups were determined by Tukey's HSD test at a level of $p<0.05$. All statistical calculations were performed using the computer program SPSS (SPSS Inc, Chicago, IL 60606, USA).

For the second part of the study, 60 extracted human molars were embedded in acrylic resin, leaving the crowns and the coronal half of the roots exposed. Box-shaped Class V cavities of 5 mm length, 3 mm height and 2 mm depth were cut at the cemento-enamel junction (CEJ) using medium- and fine-grained diamonds burs in a high-speed contra-angle handpiece with water cooling. The cervical margins were located 1 mm below CEJ in dentin. A bevel of 1 mm width was prepared at the enamel margins using fine-grained diamond burs. The enamel margins were etched for 60 seconds using 35% H_3PO_4-gel (Email Preparator GS, Vivadent), rinsed for 15 seconds and dried using compressed air. The dentin was not etched. A multi-bottle dentin bonding agent (Syntac, Vivadent, Lot #725730) was applied according to manufacturer's instructions and light cured for 10 seconds using the same curing unit that was used afterwards to irradiate the filling. The cavities were filled using a fine hybrid resin-based composite (Tetric, Shade A2), placing two increments as depicted in Figure 1. The fillings were randomly distributed into six groups and irradiated with low or high intensity curing light according to three different curing protocols:

1) *Direct Irradiation:* The light guide was placed over the center of the cavity at close distance from the cavity margins without touching them. Irradiation time per increment: 40 seconds.

2) *Distance Irradiation:* The light guide was placed over the center of the cavity at a 10 mm distance from the cavity margins. Irradiation time per increment: 40 seconds.

3) *Cervical Start Irradiation:* The light guide was initially placed beneath the cervical cavity margin facing the root of the specimen. After activation of the curing light, the light guide was moved slowly in the coronal direction and reached the coronal cavity margins after 20 seconds. Since the irradiation started outside the cavity and arrived at the coronal margins after 20 seconds, the amount of light applied up to this point was considered equivalent to 10 seconds of irradiation from the center of the cavity. Therefore, the increment was irradiated from this position for an additional 30 seconds.

The fillings were contoured and finished using flexible disks (Sof-Lex, 3M Dental Products, St Paul, MN 55144, USA). The restored teeth were stored in demineralized water at 37°C for 30 days and submitted to thermocycling (2500 cycles between 5° and 55°C, dwell time 30 seconds) after 15 days. After water storage and thermocycling, the specimens were coated with two layers of fingernail varnish to within approximately 1 mm of the tooth-restoration interface and immersed in 0.5% basic fuchsin dye for 24 hours. Using a diamond saw (WOCO 50/med, WOCO 90/3, Conrad, D-38678 Clausthal-Zellerfeld, Germany), the crowns were sectioned twice in the bucco-lingual direction parallel to the long axis of the tooth so as to divide the fillings into three approximately equal parts (cf Figure 1). On the four cross-sections, the depth of dye penetration at the cervical tooth-restoration interface was measured using a stereo microscope (Laborlux 12 ME S, Wild Leitz GmbH, D-35578 Wetzlar, Germany). For each specimen, the four readings were averaged. The differences between the treatment groups were tested for statistical significance using a two-way ANOVA. The independent variables were intensity of the curing light (two levels) and type of curing protocol (three levels).

RESULTS

The results of the first part of the study are presented in Table 1 and graphically in Figure 2. For each storage period, the differences between the irradiation protocols were highly significant (ANOVA: $p<0.001$). Groups not significantly different (Tukey: $p>0.05$) are specified in Table 1 and Figure 2 using identical letters. One hour after irradiation, Vickers hardness indicating degree of cure was highest for the high-intensity curing light without distance and the low-intensity light without distance when used for 60 seconds. With the shorter irradiation periods, the low intensity light produced inferior Vickers hardness. The lowest hardness values were observed for the high-intensity light when used from a distance of 10 mm.

From one to three and again to 24 hours, the hardness increased for all combinations of curing type and duration. After 24 hours, an equivalent Vickers hardness was observed for the high-intensity light without distance and the low-intensity light when used for 40 or 60 seconds. The hardness produced by the low-intensity light used for 20 seconds and the high-intensity light with 10-mm distance applied for 60 seconds was somewhat lower. However, this difference was not statistically significant. Only the specimens irradiated for 20 or 40 seconds using the high-intensity light from 10-mm distance showed inferior hardness values than the remaining groups.

All restorations featured a perfect marginal seal at the coronal tooth-restoration interface. The depth of dye penetration at the cervical margins is graphically presented in Figure 3. Dye penetration was more pronounced in the fillings that were photo-activated by the high- as compared to the low-intensity curing light ($p<0.05$). For both curing lights, the cervical start curing protocol produced more dye penetration than the direct or the distance irradiation ($p<0.01$), which, in turn, appear more or less equivalent. A significant interaction between the two main factors was not observed.

DISCUSSION

The results presented above support the hypothesis that reduced light intensity can sufficiently photo-activate polymerization of RBC at least for the material used in this study. The second hypothesis was only partially supported: low-intensity irradiation did improve the marginal seal of Class V RBC restorations, whereas irradiation from the cavity margin rather produced adverse effects.

The direct evaluation of the degree of cure of photo-activated resin-based composites by spectroscopic techniques is not easily accomplished. Therefore, the indirect evaluation using hardness as a parameter indicating the degree of cure is widely accepted (Ferracane, 1985; DeWald & Ferracane, 1987; Rueggeberg & Craig, 1988). In this study, the Vickers hardness increased between one, three and 24 hours after irradiation irrespective of what curing type and duration had been used. This effect is called post-irradiation curing and has already been reported in the literature (Hansen, 1983; Watts, McNaughton & Grant, 1986; Pilo & Cardash, 1992). Due to this effect, specimens irradiated by the low-intensity curing light for less than 60 seconds or the high-intensity light from 10 mm distance for 60 seconds achieved a hardness after 24 hours that was equivalent to or at least not significantly inferior to that produced by the high-intensity light used directly. This had not been the case after one or three hours. Thus, post-irradiation curing appears to be more pro-

Table 1. *Vickers Hardness [VHN 0.2/30] (mean ± SD, n=6) for the Different Treatment Groups. Identical Letters Specify Groups Not Significantly Different at a Level of* p*<0.05 (Tukey Test)*

			Time Between Irradiation and Hardness Measurement					
Distance[1]	**Intensity [mm]**	**Duration [s]**	**1 Hour**		**3 Hours**		**24 Hours**	
0	high	20	61.8 ± 1.1	α	70.0 ± 0.8	a	77.4 ± 1.6	A
		40	60.5 ± 1.0	α	67.9 ± 1.3	a	77.2 ± 1.2	A
		60	60.5 ± 1.0	α	68.2 ± 1.8	a	77.3 ± 1.5	A
10	high	20	44.2 ± 1.6	ε	57.1 ± 1.4	e	65.8 ± 1.6	C
		40	52.1 ± 1.4	δ	60.7 ± 1.3	cd	73.9 ± 2.1	B
		60	54.2 ± 1.7	ϒδ	61.6 ± 2.0	c	76.0 ± 2.0	AB
0	low	20	55.3 ± 1.3	βϒ	59.0 ± 0.8	de	75.9 ± 1.3	AB
		40	57.6 ± 0.9	β	61.2 ± 0.9	cd	77.4 ± 0.9	A
		60	60.2 ± 1.0	α	64.5 ± 0.6	d	77.8 ± 1.0	A
Result of one-way ANOVA			$p<0.001$		$p<0.001$		$p<0.001$	

[1] *between curing tip and specimen*

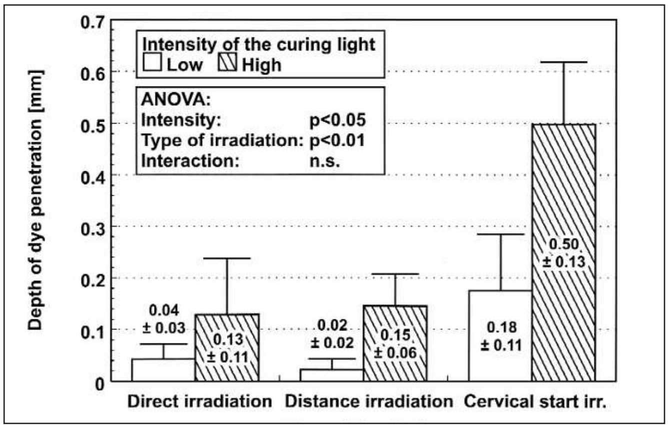

Figure 3. *Depth of dye penetration [mm] at the cervical margins (mean ± standard deviation, n=10).*

nounced in specimens irradiated at low intensity and for shorter periods. For the particular resin-based composite used in this study, irradiation by the low-intensity unit or by the high-intensity light used from 10 mm distance for 60 seconds produced equivalent hardness after 24 hours as compared to the high-intensity light used directly and therefore appears to be clinically acceptable.

According to the concept of guiding the shrinkage vectors towards the cavity margin as suggested by Lutz & others (1986), the restorations irradiated using the cervical start technique should have demonstrated less marginal leakage than the other restorations. However, the opposite was true. Lösche (1999) has demonstrated that the indirect irradiation of Class II restorations via light reflecting wedges or through the buccal or lingual cavity walls results in a considerable reduction of light intensity as compared to direct irradiation from the occlusal surface. In addition, he has shown that the favorable marginal seal achieved by the three-sited light curing technique is rather a consequence of the reduced light intensity than of the direction from which the restoration was irradiated. The cervical start technique used in this study causes the polymerization to start at the cervical margin, whereas the light intensity is not reduced in comparison to the direct irradiation technique. Therefore, the results of this study correspond to those reported by Lösche (1999). As a matter of fact, the cervical start technique even had an adverse effect on marginal seal. Possibly, the resin-based composite adjacent to the cervical cavity margin has already lost its capacity for relaxation of contraction stresses by flow (Davidson & de Gee, 1984) when the bulk of the material polymerizes and consequently creates contraction stress.

Using low-intensity curing light has produced less marginal leakage than the high-intensity light. Similar results have been reported in the literature (Uno & Asmussen, 1991; Feilzer & others, 1995; Unterbrink & others, 1995; Yoshikawa & others, 2001a,b). Irradiating the restoration from a distance of 10 mm failed to further improve the marginal seal. On the whole, the hardness measurements reported in the first part of the study indicate that this particular brand of RBC is sufficiently cured even at low intensity and, therefore, the favorable marginal seal observed in the second part is probably not at the expense of physical parameters or biocompatability. This is not necessarily true for other brands of RBC (especially with less effective photo-activation), and further studies are needed prior to transferring the present results to other materials.

CONCLUSIONS

The hybrid resin composite evaluated in this study can be successfully photo-activated even with a curing light providing 250 mW/cm^2 or with a curing unit producing 600mW/cm^2 used from 10 mm distance for 60 seconds. The low intensity unit produced less marginal leakage in Class V restorations than the high intensity light. The attempt to guide shrinkage towards the cervical margins adversely affected marginal seal.

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The Influence of a Packable Resin Composite, Conventional Resin Composite and Amalgam on Molar Cuspal Stiffness

JD Molinaro • KE Diefenderfer • JM Strother

Clinical Relevance

Packable resin composite restorations may not improve cuspal stiffness over that achieved by conventional resin composite or amalgam.

SUMMARY

Packable resin composites may offer improved properties and clinical performance over conventional resin composites or dental amalgam. This in vitro **study examined the cuspal stiffness of molars restored with a packable resin composite, a conventional posterior microfilled resin composite and amalgam. Forty-eight intact caries-free human third molars were distributed into four treatment groups (n=12) so that the mean cross-sectional areas of all groups were equal. Standardized MOD cavity preparations were made and specimens restored using one of four restorative materials: (1) a spherical particle amalgam (Tytin); (2) Tytin amalgam with a dentin adhesive liner (OptiBond Solo); (3) a conventional microfilled posterior resin composite (Heliomolar); (4) a packable posterior resin composite (Prodigy Posterior). Cuspal stiffness was measured using a Bionix 200 biomaterials testing machine (MTS). Specimens were loaded vertically to 300 N at a crosshead speed of 1.0 mm/minute. Stiffness was measured at 10 intervals: (1) prior to cavity preparation (intact); (2) following cavity preparation, but before restoration; (3) seven days after restoration; then (4) 1,2,3,4,5,6 and 12 months after restoration. All specimens were stored at 37°C in deionized water throughout the study and thermocycled (5°/55°C; 2000 cycles) monthly for 12 months. Repeated Measures ANOVA revealed significant differences among treatment groups over time (**$p<0.0001$**). Cavity preparation reduced cuspal stiffness by more than 60%. At 12 months, the cuspal stiffness of restored teeth was, on average, 58% that of intact specimens. Neither the packable nor the conventional resin composite increased cuspal stiffness over that of amalgam.**

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INTRODUCTION

Since their development by Rafael Bowen in 1962, resin composite restorative materials have demonstrated great success as anterior restorations. Their success in posterior applications, however, has been limited by their physical properties and handling characteristics. Over the years, considerable efforts have been made to improve their clinical performance as posterior restorations. Some advantages of resin composites is that they are more esthetic than amalgam, require less severe cavity preparation, thus permitting greater conservation of tooth structure and produce an immediate cavosurface marginal seal (Opdam, Feilzer & Roeters, 1998; Small, 1998). Conversely, when compared to amalgam, disadvantages of resin composites include greater technique sensitivity and more limited clinical applications. In addition, they are more time consuming and expensive to place than amalgam (Small, 1998; Van Dijken, Hörstedt & Waern, 1998; Christensen, 1999).

Success of Posterior Resin Composites. In clinical situations where esthetics is a primary concern for the patient, practitioners have historically substituted conventional resin composites for posterior amalgam restorations. Typically, early posterior resin composite restorations exhibited severe leakage, secondary caries, higher rates of occlusal wear than amalgam (Leinfelder, 1987; Mazer, Leinfelder & Russell, 1992; Suzuki, Suzuki & Cox, 1996) and severe loss of anatomical form (Leinfelder & Roberson, 1983). More recent materials generally possess higher concentrations of inorganic filler. As a result, the high rates of occlusal wear exhibited by earlier materials have been reduced (Suzuki & Leinfelder, 1993; Söderholm & Richards, 1998). However, although the physical and mechanical properties of posterior resin composites have been improved, case selection and attention to detail when placing these restorations remain critical (Small, 1998; Nash, Lowe & Leinfelder, 2001). Contraindications include heavy occlusion or bruxism, subgingival margins, the inability to obtain adequate isolation, poor oral hygiene and high caries risk. Furthermore, practitioners must be aware that their handling characteristics and cavity designs differ from those associated with conventional amalgam (Leinfelder, 1996).

The success of a restoration also depends on such clinical factors as the extent of caries, the presence of existing restorations and the extent of the tooth preparation (Leinfelder & Roberson, 1983). Several studies have demonstrated that cavity preparation can significantly weaken remaining tooth structure (Vale, 1956; Grimaldi & Hood, 1973; Mondelli & others, 1980; Eakle, 1986; Stampalia & others, 1986; Joynt & others, 1987). Blaser & others (1983) demonstrated that preparations with wide intercuspal dimensions and deep pulpal floors were more prone to cause fracturing of tooth structure than those with narrow dimensions and shallow pulpal floors. Similarly, a narrow isthmus with a deep pulpal floor had a greater weakening effect than a wide isthmus and a shallow pulpal floor. In endodontically-treated posterior teeth, the main problem may be the depth of the cavity preparation, as the pulp chamber floor becomes the cavity floor (Panitvisai & Messer, 1995). A conservative cavity design or a conservative endodontic access will decrease the likelihood of tooth or restoration fracture.

Cuspal Fracture. Cusp fracture is a significant clinical problem with large, undermined preparations and restorative materials that do not reinforce the teeth. In conservative preparations, restoration with amalgam or resin composite may regain at least a portion of the tooth's original strength (Eakle, 1986; Gelb, Barouch & Simonsen, 1986; Joynt & others, 1987). Some studies have reported greater effectiveness with bonded resin composites than non-bonded amalgam (Gelb & others, 1986; Jagadish & Yogesh, 1990; Liberman & others, 1990), while others have reported similar results for the two materials (Stampalia & others, 1986; Joynt & others, 1987; Sheth, Fuller & Jensen, 1988; Boyer & Roth, 1994). Bonded amalgam restorations may provide, at least in the short term, substantial improvement over non-bonded amalgam restorations (Eakle, Staninec & Lacy, 1992; Boyer & Roth, 1994), although reports have been inconsistent (Santos & Meiers, 1994; Bonilla & White, 1996). However, in more extensive preparations, neither amalgam (bonded or non-bonded) nor resin composite may be effective in restoring cuspal strength (Boyer & Roth, 1994; Steele & Johnson, 1999; Allara, Diefenderfer & Molinaro, 2001).

Cuspal Flexure. Cuspal flexure is a normal physiologic process necessary to prevent brittle fracture. Average masticatory forces on incisors, canines and premolars have been reported to be approximately 150, 200 and 300 N, respectively, while biting forces on first and second molars range from 400 to 800 N (Craig, 1997). Both the size of the cavity preparation and the choice of restorative material may affect cuspal flexure during occlusal loading. Evaluating premolars restored with posterior resin composites, Suliman, Boyer & Lakes (1993) reported less cusp movement in teeth with smaller cavity preparations (1.9 mm width x 2.0 mm depth) than in those with larger preparations (3.4 mm width x 4.0 mm depth). Morin, DeLong & Douglas (1984) compared cuspal deformation in maxillary premolars restored using bonded resin composite with those restored using non-bonded amalgam. Following removal of an occlusal load, amalgam restorations experienced recovery of cuspal deformation at a much slower rate than resin composite restorations. However, in a similar study of maxillary premolars restored with either a non-bonded amalgam or a resin composite, Medige & others (1995) reported no statistically significant differences in the recovery of the cusps based on the restorative material used.

Packable Resin Composites as Posterior Restorations. A recent innovation in posterior resin composite materials is the incorporation of coarse ceramic fibers (aluminum oxide and silicon dioxide) in addition to, or in place of, conventional inorganic filler particles. These new fillers impart a "condensable" characteristic previously not present in resin composite restorative materials (Leinfelder, Bayne & Swift, 1999). Compared to incrementally placed resins, some potential advantages of packable resin composites include increased wear resistance, decreased polymerization shrinkage and increased depth of cure (Söderhölm & Richards, 1998; Leinfelder & others, 1999; Jackson & Morgan, 2000).

Increased wear resistance is generally attributed to reduced filler particle size and increased filler loading (Suzuki & others, 1995; Condon & Ferracane, 1997). The filler volume of currently available packable resin composites ranges from approximately 45% to 70% (Leinfelder & others, 1999; Choi & others, 2000), which is not substantially different from that of non-packable microfine and hybrid composites (O'Brien, 1997). Wear resistance, however, appears to be product-specific, with results varying depending on laboratory methodology. Ferracane, Choi & Condon (1999) reported no significant differences in the wear resistance of packable and non-packable composites. Manhart & others (2000) reported that two packable resin composites (Solitaire, SureFil) demonstrated significantly greater wear resistance, while a third packable material (ALERT) exhibited significantly lower wear resistance compared to a non-packable hybrid resin composite (Tetric Ceram).

A decrease in polymerization shrinkage results in less build-up of internal contraction stresses, a reduction in the formation of contraction gaps or voids and a decrease in cuspal deformation (Ehrnford, 1981). According to Jørgensen & Hisamitsu (1984), cavosurface contraction gaps in resin composite restorations can be decreased by using a packable resin composite and adequate condensation force. They suggested that during condensation, the film thickness of monomer between stress-bearing areas of synthetic glass or prepolymerized resin is reduced. As a result, the linear polymerization contraction of the packable resin composite is reduced. The authors also suggested that relaxation of the elastic strain induced in the filler particles during condensation compensates for the residual linear contraction during polymerization. However, Choi & others (2000) found no improvement in the polymerization shrinkage values of five packable resin composites as compared to two non-packable composites. In addition, Chen & others (2001) reported that packable resin composites exhibited significantly higher maximum contraction stresses and greater shrinkage force rates than did conventional hybrid resin composites.

Depth of cure can be influenced by several factors, including resin shade and filler type, but at curing depths of two millimeters or more, the predominant factors are light source intensity and duration of exposure (Rueggeberg & others, 1993). An increased depth of cure allows for bulk placement or placement of larger increments of restorative material that speeds the restoration process. When packable resins were first introduced, many manufacturers claimed depths of cure of four to five millimeters (Jackson & Morgan, 2000), with some claiming curing depths of up to seven millimeters (Leinfelder & others, 1999). However, results of several independent studies have generally confirmed that most packable resins exhibit no greater depth of cure than conventional resins. Therefore, incremental placement, with increments not exceeding two millimeters in depth, remains recommended over bulk placement (Choi & others, 2000; Cobb & others, 2000; Yap, 2000).

If packable resin composite restorative materials are to be a substitute for amalgam, they should strengthen teeth, promote minimal cusp flexure, exhibit minimal occlusal and opposing tooth wear and have favorable handling characteristics (Jackson & Morgan, 2000). Currently, no information regarding the long-term strengthening of cusps by packable resin composites exists; and no long-term studies have compared their influence on cusp stiffness with that of conventional resin composite, conventional amalgam and bonded amalgam restorations. Therefore, this *in vitro* study compared cusp stiffness in teeth restored using a packable resin composite with that of teeth restored using amalgam (with and without a bonding agent) or an incrementally placed conventional resin composite.

METHODS AND MATERIALS

Forty-eight intact, extracted human third molars, free of caries or visible defects, were stored in 0.2% aqueous sodium azide at 37°C until ready for use. Twenty-four hours prior to beginning the study, these teeth were transferred to deionized water and stored at 37°C throughout the study. Specimens were mounted vertically in phenolic rings (Buehler Ltd, Lake Bluff, IL 60044, USA) using auto-polymerizing acrylic resin (Caulk/Dentsply, Milford, DE 19963, USA) to a level 2.0 mm below the CEJ. The resin bases were trimmed to expose the root apices of each specimen. Using digital calipers (Mitutoyo Corp, Tokyo, Japan), the buccolingual and mesiodistal dimensions at the CEJ were measured and a cross-sectional area (mm^2) was calculated for each specimen. Specimens were then distributed into four treatment groups (n=12) so that the mean cross-sectional areas of all groups were equal. The occlusal surfaces of all specimens were filed to create 90º buccal-lingual intercuspal angles.

Standardized MOD cavity preparations were made in all specimens using a #56 plain fissure bur in a high-speed handpiece with water coolant. Specimens were prepared in random order, and a new bur was used

Table 1: *Treatment Groups (n=12)*

Group	Restorative Material	Liner
1	Tytin	Copalite copal varnish
2	Tytin	OptiBond Solo
3	Heliomolar	OptiBond Solo
4	Prodigy Posterior	OptiBond Solo

after every fifth preparation. For each specimen, the preparation width was half its pre-measured buccal-lingual dimension. The depth of each preparation was 4.0 mm from the marginal ridge; the resulting cavity preparation was essentially a MOD slot, as no mesial or distal proximal boxes were prepared.

Specimens were restored, again in random order, using one of three restorative materials: (1) a fast-set spherical amalgam alloy (Tytin, Kerr, Romulus, MI 48174, USA); (2) an incrementally placed microfilled posterior resin composite (Heliomolar, Ivoclar North America, Amherst, NY 14228, USA) or (3) a packable resin composite (Prodigy Posterior, Kerr). Amalgam restorations were lined with either copal varnish (Copalite, Harry J Bosworth Company, Skokie, IL 60076, USA) or a fifth-generation dentin adhesive system (OptiBond Solo, Kerr); all resin composite restorations were lined with OptiBond Solo. The four treatment groups are listed in Table 1.

Specimens receiving amalgam restorations with copal varnish (Group 1) were rinsed for 20 seconds, air dried for five seconds, then coated with two consecutive layers of copal varnish. Specimens receiving amalgam restorations with OptiBond Solo (Group 2) were first etched for 15 seconds with 37% phosphoric acid gel ("total-etch" technique), then rinsed for 20 seconds, and blotted dry. OptiBond Solo was applied according to the manufacturer's instructions and light cured for 40 seconds. All amalgam restorations were condensed, burnished and carved immediately to produce a 90º intercuspal angle.

Specimens receiving Heliomolar (Group 3) and Prodigy Posterior (Group 4) were etched and dried as described above. OptiBond Solo was applied according to the manufacturer's instructions. Each cavity preparation was filled in 2.0 mm increments, with each increment light cured for 60 seconds from five directions (occlusal, buccal, lingual, mesial and distal) using a Demetron 400 curing light (Demetron/Kerr). Following 24 hours storage in 37ºC deionized water, restorations were finished with 12-fluted carbide finishing burs to produce a 90º intercuspal angle.

The cuspal stiffness of each specimen was measured using a Bionix 200 biomaterials testing machine (MTS, Inc, Cary, NC 27511, USA). A stainless steel rod (6.0 mm diameter x 16.0 mm long) was positioned over the occlusal table so that it contacted only tooth structure along the 90° intercuspal angle. Specimens were loaded vertically to a maximum of 300 N at a crosshead speed of 1.0 mm/minute. Vertical displacement (mm) of the crosshead as a function of the applied force (N) over time was recorded, the resultant curve plotted and cuspal stiffness (N/mm) determined by the MTS software as the slope of the line at its steepest aspect. For each specimen, triplicate measurements were performed and an average stiffness value calculated. Mean (± SD) cuspal stiffness was recorded for each treatment group at three intervals: (1) prior to cavity preparation (intact); (2) 24 hours following cavity preparation (pre-treatment) and (3) following restoration, seven days storage in 37ºC deionized water, and thermocycling (Willytec, Munich, Germany; 5º ± 5ºC/55º ± 5ºC; 2000 cycles; 30 second dwell time). Specimens were then returned to 37ºC deionized water for extended storage. Cuspal stiffness was measured monthly for six consecutive months, and again at 12 months. When not being tested, specimens were stored in 37ºC deionized water and thermocycled (5º ± 5ºC/55º ± 5ºC; 2000 cycles; 30 second dwell time) once per month for the duration of the study.

The data were analyzed using Repeated Measures ANOVA and, where appropriate, paired samples *t*-tests and Tukey HSD post hoc tests (α=0.05) to determine significant differences (1) among the four treatment groups at each time interval and (2) within each treatment group over time.

RESULTS

Mean cuspal stiffness values for each treatment group over time are presented in Figure 1. Two specimens from Group 3 were accidentally fractured, one during Month 4 and one during Month 5 of testing and eliminated from subsequent analyses.

Repeated measures ANOVA (Table 2) revealed that while the main effect of restorative material alone was not significant (p=0.166), the effects of time (p<0.0001) and the material by time interaction (p<0.0001) were significant. Cavity preparation reduced cuspal stiffness by over 60%. At seven days, none of the restorative treatments increased cuspal stiffness over that of prepared teeth (paired *t*-tests, all p>0.34). However, for all treatment groups, cuspal stiffness increased by an

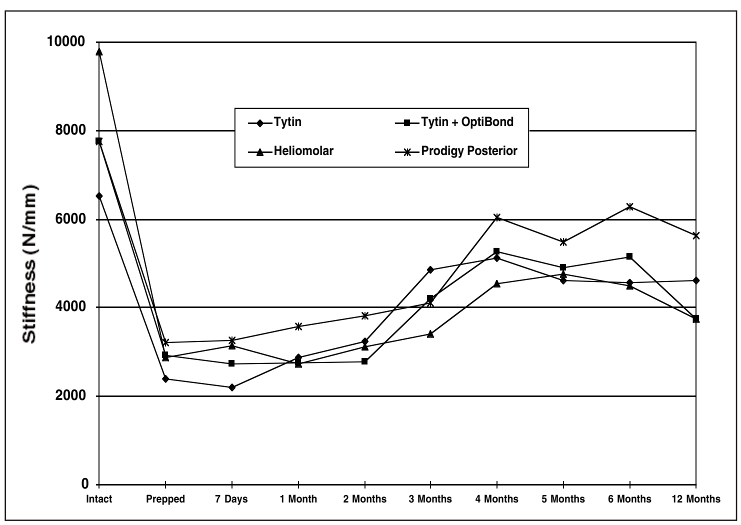

Figure 1. *Mean cuspal stiffness (N/mm) (n=12).*

Table 2: *Repeated Measures ANOVA**

Effect	*df*	F Value	Sig
Material	3	2.44	0.166
Time	7	58.21	<0.0001
Material* Time	21	4.14	<0.0001

*Cuspal stiffness measured at 10 time intervals from Intact to 12 months.

average of 13% after two months and by an additional 32% after three months over that of prepared teeth. Cuspal stiffness of restored teeth peaked at four months to an average of 84% greater than that of prepared teeth but remained 32% less than that of intact teeth. Cuspal stiffness remained relatively unchanged between four and 12 months for Groups 1 and 4 (paired *t*-tests, all $p>0.198$), but decreased for Groups 2 and 3 (paired t-tests, all $p<0.016$). At 12 months, the cuspal stiffness of restored teeth was, on average, 58% that of intact specimens; however, Groups 1 and 4 had regained a greater portion of their intact stiffness (71% and 73%, respectively) than had Groups 2 and 3 (48% and 38%, respectively). Tukey HSD post hoc analysis revealed that at 12 months the mean cuspal stiffness of Group 4 was significantly greater than that of Groups 2 and 3; Groups 1, 2 and 3 were statistically similar, as were Groups 1 and 4.

DISCUSSION

An ideal restorative material not only restores the decayed or defective tooth but also strengthens the tooth and provides an effective seal between the restoration and the tooth (Jagadish & Yogesh, 1990). In this study, as shown in others (Mondelli & others, 1980; Blaser & others, 1983; Gelb & others, 1986; Joynt & others, 1987), the strength of the teeth was reduced significantly by cavity preparation. Bell, Smith & de Pont (1982) suggested that cusp fracture occurs as a result of brittle tooth structure fatigue caused by the propagation of microcracks under repeated loadings; the use of adhesive restorative materials was considered to strengthen the teeth. Dentin-bonded resin composites have been shown to be effective in improving cuspal strength when used in conservative cavity preparations (Eakle, 1986; Gelb & others, 1986; McCullock & Smith, 1986; Liberman & others, 1990; Boyer & Roth, 1994). Cuspal strengthening by bonded amalgam restorations, however, has been less predictable (Santos & Meiers, 1994; Bonilla & White, 1996; Oliveira, Cochran & Moore, 1996), particularly when more extensive cavity preparations are evaluated (Boyer & Roth, 1994; Lindemuth, Hagge & Broome, 2000). Nevertheless, in light of the continual improvements sought and claimed by manufacturers of dentin adhesive systems, in the current study, the authors hypothesized that using bonding agents might reinforce the cusps of specimens restored with both amalgam and resin composite restorations. However, in no group was cuspal stiffness returned to that of intact, unprepared teeth.

The increase in cuspal stiffness observed between months one and four of this study was unexpected and difficult to explain. Because similar increases occurred among all four treatment groups, the authors suspect a change in the inherent stiffness of the extracted teeth as a result of aging and repeated thermocycling may be responsible. It should be noted that the specimens were never removed from water for more than a few minutes during any phase of the study and that there are few, if any, similar studies of this duration currently available in the literature for comparison of intermediate changes in stiffness over time. It is possible that the increase was due to an error in calibration of the testing apparatus. However, this is highly unlikely as the calibration was verified by a manufacturer-certified technician prior to, during and after completion of the study and never required adjustment. Another possible cause may be water sorption by the restorative materials and/or the acrylic resin bases. Measuring the stiffness of these materials alone and that of intact extracted teeth over the same 12-month period may provide additional insight.

The decreases in cuspal stiffness observed for Groups 2 and 3 between months four and 12 are less perplexing. Previous studies have suggested that resin-to-enamel and resin-to-dentin bonds hydrolyze over time (Nakabayashi, Ashizawa & Nakamura, 1992; Armstrong, Keller & Boyer, 2001; Hashimoto & others, 2001). This may explain the decrease in stiffness of the bonded amalgam and conventional resin composite restorations. In contrast, Group 4 demonstrated no decrease in cuspal stiffness between months four and 12. It is possible that bonding between the resin adhesive and the packable resin composite remains more stable over time. Similarly, non-bonded amalgam restorations (Group 1) reached an apparent equilibrium at approximately three months, as cuspal stiffness remained unchanged from three to 12 months. As stated previously, statistical analysis revealed a significant group-by-time interaction. Thus, the results of this study cannot be explained solely by differences among the restorative materials alone. Longer-term *in vitro* and *in vivo* studies are needed to delineate the nature of these dynamic interactions.

The cavity preparation used in this study was one-half the intercuspal width (a relatively wide preparation). The strengthening effect gained from bonding systems is likely to be clinically less significant in conservative preparations because of the large bulk of remaining tooth structure than in similar teeth with wider preparations where the cusps have less support (Eakle, 1986; Dias de Souza & others, 2001). Indirect resin restorations in large MOD preparations in maxillary premolars have been shown to recover tooth stiffness to a level similar to that of the sound tooth (Lopes, Leitao & Douglas, 1991). The authors suggested that this was a result of the high bond strength between the restoration and tooth and the high degree of stiffness of the restorative material. However, the literature also suggests that there remains a critical preparation width, beyond which a conventional non-bonded direct restorative material is incapable of recovering cuspal strength (Boyer & Roth, 1994; Geurtsen & García-Godoy, 1999; Davis, 2001). This study suggests that, in spite of improvements in resin bonding, the same is true for bonded direct restorative materials. Therefore, practitioners should consider indirect restorations (cast metal, bonded ceramic or bonded resin-based composite) when the cavity preparation exceeds one-half the intercuspal width (Geurtsen & García-Godoy, 1999).

A tooth's response to occlusal loading can be evaluated by measuring fracture strength, cusp flexure or cusp stiffness. Fracture strength measurement is the simplest to perform but is a destructive test that may not always simulate *in vivo* conditions because the forces required to fracture specimens *in vitro* may not occur in the oral cavity (De Boever & others, 1978; Craig, 1997; el-Badrawy, 1999). In contrast, cusp flexure and cusp stiffness measurements are considered non-destructive methods that better lend themselves to repeated measures studies (el-Badrawy, 1999), and the loads applied to the specimens are similar to *in vivo* conditions (Reeh, Douglas & Messer, 1989).

The technique used is this study is similar to that used by Grimaldi & Hood (1973). In their study, the load was applied via a steel ball placed in the occlusal fossa of each specimen; deflection of individual cusps was measured directly by linear voltage differential transformers. The authors concluded that: (1) breaking the continuity of the enamel layer significantly reduces tooth rigidity; (2) progressive tooth removal increases cusp flexibility and (3) a preparation with a narrower isthmus is more rigid than one with a wide isthmus.

Hood (1991) proposed that in Class II cavity preparations the weakened cusps could be considered to behave

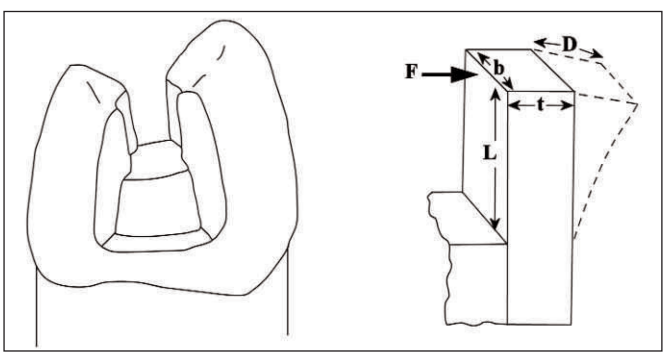

Figure 2. *Comparison between deflection of cantilever beam and cusp of MOD cavity preparation.**
** Adapted from Hood *(1991). Reprinted with permission of* International Dental Journal *and* FDI World Dental Press.

as cantilever beams. When teeth are subjected to occlusal loads, doubling cusp height does not simply double the cuspal deflection but would increase it by about eight times (Figure 2). Using the formulas:

$$D=L^3F/3EI \quad \text{and} \quad I=bt^3/64$$

where

D = deflection

F = force

E = elastic modulus

L = length or depth of cavity preparation

I = moment of inertia

b = breadth or mesiodistal length

t = thickness of the cusp

Hood speculated that as cusp height doubled due to an increase in cavity floor depth (L), the deflection increased by a factor of eight due to the L^3 factor. Similarly, if cusp width (t) is reduced by one-half, deflection would also increase eight-fold due to the t^3 factor, resulting in a corresponding increase in stress at the internal line angles. If the cantilever beam hypothesis is valid, then it should be possible to measure cusp flexure either by linear displacement of the cusp or by the strain generated in the cusp as it flexes (Jantarat & others, 2001).

Jantarat & others (2001) used both strain gauges and direct current differential transformers to measure cuspal deformation. They observed that correctly positioned strain gauges are more practical than linear displacement devices, and furthermore, disagreed with Hood (1991), suggesting that cusps do not behave as simple rectangular beams since cusp morphology and cavity designs are geometrically more complex than a simple cantilever beam. Their data suggest that cusps are sufficiently rigid and do not flex much when the fulcrum shifts to the floor of the pulp chamber. Therefore, the formula for a simple beam cannot apply when measuring cusp flexure. In addition, forces generated intraorally during function vary in magnitude, direction and speed of application, whereas in the laboratory setting, forces are typically applied to teeth in a constant direction and at a constant speed (Bell & others, 1982; Eakle, 1986; Jagadish & Yogesh, 1990). Cuspal fracture *in vivo* can occur not only due to acute traumatic force, but also as a result of progressive fatigue under repeated intraoral loading (Eakle, 1986).

Measuring cuspal deflection using electrical strain gauges was previously reported to provide clinically relevant results (Morin & others, 1984; Lopes & others, 1991). However, the authors did not report the use of thermocycling regimens in their studies. Using strain gauges bonded to the buccal and lingual cusps of each specimen, el-Badrawy (1999) intended to measure cuspal deflection after every 1,000 thermocycles for a total of

8,000 cycles. However, he reported that following thermocycling, the strain gauges failed to respond reliably.

The stiffness of a material, as represented by its elastic modulus, is a measure of the material's ability to resist elastic deformation. The elastic modulus is defined as the ratio of stress (the resistance developed within a material in response to an external force) to strain (the deformation caused by the applied force). The property of elasticity is characterized by a constant ratio of stress to strain. Therefore, the resultant stress-strain curve is linear (until the proportional limit is reached), and the elastic modulus represents the slope of the stress-strain curve over this linear, or elastic, range of the material (Craig, 1997; O'Brien, 1997).

The elastic modulus is an inherent, fundamental property that is dependent on a material's composition and cannot be altered substantially by heat treatment or other conditioning that may alter the material's microstructure. For homogeneous materials, calculating the elastic modulus is relatively uncomplicated. Human enamel exhibits an *in vitro* elastic modulus roughly five times that of dentin; the elastic modulus of dental amalgam is about 50% greater than dentin, while the elastic modulus of resin composites is very comparable to dentin (Craig, 1997). However, determining deformation behavior in systems containing two or more physically distinct components can be quite complex. Suresh (1998) described the derivation of two mathematical models using tangent moduli to calculate total strain increment in uniaxial deformation. In these models, both the linear (elastic) and non-linear (plastic) moduli are included in the calculation of the tangent modulus; however, within the elastic range, the tangent modulus is unaffected by the value of the plastic modulus. Therefore, unless a material's stress-strain curve exhibits predominantly plastic behavior, the tangent modulus will, by definition, correspond with the elastic modulus. Moreover, these models were developed to describe the phenomenon of work hardening in metals; their application to *in vitro* or *in vivo* dental models has not been clearly shown. In this study, maximum occlusal loading was limited to 300 N, well within physiologic limits, and well within the elastic range of all specimens. As shown in Figure 3, stiffness was calculated along the steepest aspect of the slope of the linear portion of the stress-strain curve.

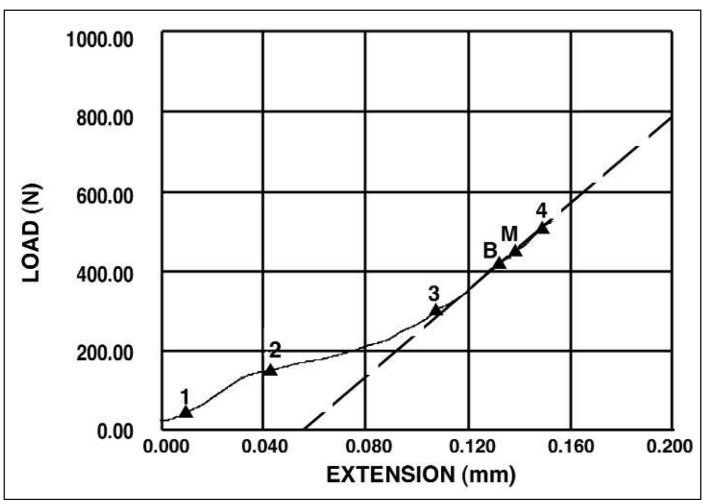

Figure 3. *Representative stress-strain graph.*
1 = deflection at 50 N load point
2 = deflection at 150 N load point
3 = deflection at 300 N load point
4 = deflection at 500 N load point
B - M = interval of steepest slope as determined by MTS software

Cuspal displacement and cuspal flexure (µm) may be more easily understood parameters than stiffness (N/mm). However, because the currently available methodologies (that is, strain gauges and linear variable differential transformers) required for measuring cuspal displacement do not lend themselves well to long-term study designs, and because of the paucity of literature available on the long-term performance of these newer materials, the authors chose an alternative methodology that they were confident would provide reliable data over the long-term, even though the parameter (stiffness) may be less intuitive. If a reliable technique that enables strain gauges to withstand thermocycling and extended water storage can be developed, then strain gauges should be utilized to measure cuspal deflection in long-term studies. In addition, until a measuring device that accurately reproduces the different intraoral characteristics of applied loads (magnitude, direction and speed) has been developed and is readily available, traditional laboratory methods utilizing unidirectional static loading will, by necessity, continue. Studies of *in vitro* fracture strength can provide useful preliminary information. However, more sophisticated long-term laboratory studies and long-term clinical evaluations are required.

CONCLUSIONS

The long-term reinforcement of weakened tooth structure when using directly placed intracoronal restorative materials remains a clinical challenge. Compared to incrementally-placed posterior resin composites, packable resins offer the potential for improved physical properties and ease of use. However, although some studies have reported favorable handling characteristics, the physical properties of packable resins appear to be no better than those of conventional resins. Moreover, their long-term clinical performance, compared to conventional resin composites or dental amalgam, has not yet been substantiated.

Under the conditions of this study, extensive MOD cavity preparation reduced molar cuspal stiffness by more than 60%. Conventional resin composite and bonded amalgam restorations demonstrated decreasing cuspal stiffness during the final six months of evaluation, while packable resin composite and non-bonded amalgam restorations did not. Neither packable nor conventional resin composite increased cuspal stiffness over that of amalgam, and none of the direct placement materials evaluated restored the cuspal strength lost during cavity preparation. Therefore, practitioners should consider indirect cast metal or ceramic restorations when the strength of remaining tooth structure is in question.

Disclaimer

The opinions expressed in this article are the private views of the authors and should not be construed as reflecting official policies of the US Navy, Department of Defense or US Government.

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Technique on Restoring Cervical Lesions

BA Matis • MA Cochran

Clinical Relevance

This is a technique for restoring cervical lesions that extend subgingivally.

SUMMARY

This paper describes a technique of placing a semi-rigid cervical matrix slightly past the cervical border of a lesion that extends below (apical to) the gingival crest and inserting the glass ionomer cement through an opening cut in the matrix above the soft tissue level.

INTRODUCTION

Restoration of cervical lesions that extend below the soft tissue present special challenges. Such lesions appear when we inform and convince patients not to abrade their hard tissues during brushing and leave them unrestored. Often, soft tissues recontour themselves and cover part of the abraded area. The access for restoring such lesions becomes difficult.

There are four ways that practitioners have overcome this concern. The first is crown lengthening. Sometimes, this produces an unacceptable esthetic result when it is accomplished in the maxillary anterior sections. The second way is to retract the tissues with a retraction clamp such as a 212, using a compound, so that it is stabilized. This works well unless the cervical margin of the lesion is so low that tearing of the tissue would occur if the soft tissue was raised to that height with a retractor. The third method involves the use of surgical releasing incisions or preparation of a "mini-flap" prior to retractor placement. This technique requires healing time and can affect the gingival height of contour.

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The fourth method that has been used successfully is placing a matrix under the tissue that will contour the restoration so that minimal finishing is required. This method uses a semi-rigid cervical matrix, such as the Hawe-Neos Dental Cervical Matrix (Hawe-Neos Dental, Bioggio, Switzerland). The material of choice is a conventional glass ionomer, where contamination is not present but absolute control of water is not a necessity. The method described here uses Ketac-Fil that has been shown to abrade minimally (Matis & others, 1991) and has excellent retention (Matis & others, 1996).

The authors have confirmed that the pocket on tooth #6 is 3 mm in depth and the lesion extends almost 2.5 mm below the height of soft tissue (Figure 1). A matrix was chosen for placement that follows the contour of the lesion (Figure 2). We placed the matrix into position and contoured it to approximate the restoration

Figure 1. *Perio probe indicating cervical extent of lesion.*

Figure 2. *Selected matrix before contouring.*

Figure 3. *Contoured matrix positioned and marked at incisal extent.*

Figure 4. *Matrix placed against incisal mark showing degree of extension subgingivally.*

Figure 5. *Access hole for insertion of glass ionomer restorative.*

Figure 6. *Conditioned lesion with matrix in place.*

Figure 7. *Insertion of glass ionomer cement.*

desired, then marked the incisal extent of the matrix with a pencil (Figure 3). Figure 4 shows the matrix on the outside of the tooth with the incisal marking in place. This allows the practitioner to determine where the hole will be positioned into which the restorative material will be placed (Figure 5).

The lesion is then conditioned with polyacrylic acid for 20 seconds with the matrix extended slightly, then rinsed thoroughly (Figure 6). The glass ionomer is mixed in a triturator and placed into the lesion through the hole until the material exudes from the sides of the matrix (Figure 7). Light pressure is kept on the matrix so that it is not displaced from its correct position. If it has been contoured properly, the matrix will not move if held in place with light pressure. Glaze is place circumferentially to reduce the possibility of salivary contamination or desiccation, if exposed to air (Figure 8). The material is allowed to cure for 15 minutes.

The restoration is coated with Ketac Glaze as soon as the matix is moved (Figure 9). The material is easy to

Figure 8. *Glass ionomer cement in place and glaze applied.*

Figure 9. *Removal of matrix and re-application of glaze.*

Figure 10. *Finished restoration immediately post-op.*

Figure 11. *Finished restoration at three months.*

contour with a #12 blade in Bard Parker handle. The final restoration immediately after finishing (Figure 10) needs to cure for 24 hours before final color is evident. Figure 11 shows the restoration three months after placement.

Some periodontists feel that this lesion needs no restoration. They are concerned about injury to the integrity of the tooth, especially from finishing procedures. With the protected environment, others feel it needs to be restored. Where sensitivity is present in such a lesion, the universal treatment is restoration of the lesion. All praactitioners agree that we need to be very cautious not to interrupt the surface of the tooth or make margins subgingivally, which will be detrimental to tissue health. This method can be used without using rotary instruments, as conventional glass iomoners remain easy to finish with hand instruments for an abbreviated time after placement. This technique can be used on any teeth where the lesion is partially located subgingival and on any of the accessible surfaces, either labial or lingual.

Using this method and material, subgingival lesions can be restored to appropriate form and contour.

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Commentary

Failure, Repair, Refurbishing and Longevity of Restorations

IA Mjör • VV Gordan

Clinical Relevance

Repair and refurbishing as alternatives for replacement of restorations save tooth structure.

SUMMARY

The clinical diagnosis of secondary caries is the main reason for replacement of all types of directly-placed restorations. This is an ill-defined clinical diagnosis both in teaching programs and in general practice. The criteria for the diagnosis must be improved and come in line with those for primary caries.

Secondary caries are usually localized and delineated lesions and should be differentiated from stained and ditched margins. Small defects of secondary caries, stained and degraded margins may be removed by refurbishing/refinishing procedures. Larger defects may be explored by removing part of the restoration to access the defective margin. By removing part of the restoration to the full depth, a firm diagnosis can be made regarding the extent of the lesion, as the defects are often well delineated. Provided the main part of the restoration is satisfactory, the "exploratory" cavity preparation can then be filled with an appropriate material.

These approaches will save tooth structure and be cost-effective. However, longevity data are lacking with such studies in progress.

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FAILURE, REPAIR, REFURBISHING AND LONGEVITY OF RESTORATION

The teaching and practice of operative dentistry have traditionally focused on optimal care. Textbooks are replete with examples on how to achieve ideal restorations. Less attention is paid to the diagnosis and treatment of failed restorations. Whenever restorations are examined clinically, deviations from the ideal are common. This review focuses on minimal operative intervention as it applies to restorations that have been clinically diagnosed with failures that commonly result in replacement of restorations. The basis and rationale for these replacements will be discussed and alternative treatments considered.

Failure of Restorations

Replacements of restorations in general dental practice are based on a limited number of criteria (Mjör, 1981; Mjör, Moorhead & Dahl, 2000a):

Secondary Caries

Discoloration

- Bulk
- Margin

Fracture of Restoration

Bulk

Margin

Fracture of Tooth

Bulk (cusp)

Margin (enamel)

Poor Anatomic Form

Other Reasons

Recent practice-based studies have confirmed that secondary caries (about 50%) and fracture (about 25%) are the two most frequently sited reasons for restoration replacement. Discoloration as a criterion for failure is only applicable for tooth-colored restorations and is mainly used for resin based materials (15%). Tooth fracture is given as reasons for replacement in 7% of all replaced amalgam restorations, while 4% of all other directly placed restorations are replaced with this diagnosis. Poor anatomic form, reflecting degradation of the material, was a particularly relevant criterion when silicate cement was used and also for the first developed resin-based composite materials (Mjör, 1981), but with the present composite materials, marginal degradation is a minor problem. However, traditional glass ionomer materials are reported to fail due to poor anatomic form (Mjör & others, 2000a). Restorations that lack contact with adjacent teeth are also listed as poor anatomic form. This defect is usually of iatrogenic origin.

The reasons for restorations outlined above are similar to those outlined in the USPHS/Ryge system for evaluation of restorations (Ryge, 1972; Ryge & Snyder, 1972; CDA, 1977). This system is the only internationally accepted method for assessment of restorations. Evaluations using this system require calibration of the examiners, but calibrations are not usually part of teaching programs or continuing education courses. The present review will focus on reasons for replacement of restorations in cross sectional studies in general dental practice, that is, the recordings were made by non-calibrated clinicians. The clinical diagnoses of secondary caries and restoration discoloration, especially at the margins and fracture of restorations, are the main reasons for failure of restorations that will be discussed in this paper.

No specific definition has been presented for what degree or extent a defect is acceptable or unacceptable, requiring restoration replacement. Thus, it must be recognized that defects leading to the diagnosis of a failure are subjective. This situation explains the marked variation in a clinician's treatment decisions (Bader & Shugars, 1992)

Failure of restorations may affect the entire restoration, or they may be due to localized defects such as marginal staining and secondary caries. The major defects that lead to displacement of restorations will be discussed under two major headings: Marginal Discrepancies and Bulk Failures. Generally speaking, localized defects lend themselves more readily to repair and refurbishment than defects involving the entire restorations.

Marginal Discrepancies

Secondary Caries and Stained Margins

The clinical diagnosis of secondary caries is by far the most common reason for replacement of all types of direct and some types of indirect restorations in general dental practice (Mjör, 1981; Klausner, Green & Charbeneau, 1987; Mjör & others 2000a), comprising 50-60% of all restorations replaced. This diagnosis is poorly defined (Mjör & Toffenetti, 2000) and subjective, even as taught in dental schools (Clark & Mjör, 2001). Despite the uncertainty associated with the diagnosis of secondary caries, the diagnosis leads to replacement of restorations and results in an increase in the size of the subsequent restoration (Figure 1) (Elderton, 1977; Mjör & others, 1998; Gordan, 2000, 2001; Gordan, Mondragon & Shen, 2002). Secondary caries is a localized defect usually found at the gingival aspect of restorations (Mjör, 1985; Mjör & Qvist, 1997; Mjör, 1998). Alternatives to replacement of restorations with the diagnosis of secondary caries must, therefore, be sought to save tooth tissues and reduce the long-term cost of restorative dental care.

The differential diagnosis between stained margins of tooth-colored restorations and secondary caries is difficult (Figure 2) (Tyas, 1991; Kidd, Joyston-Bechal & Beighton, 1995). This uncertainty undoubtedly ties in with the emphasis placed on "microleakage" at the

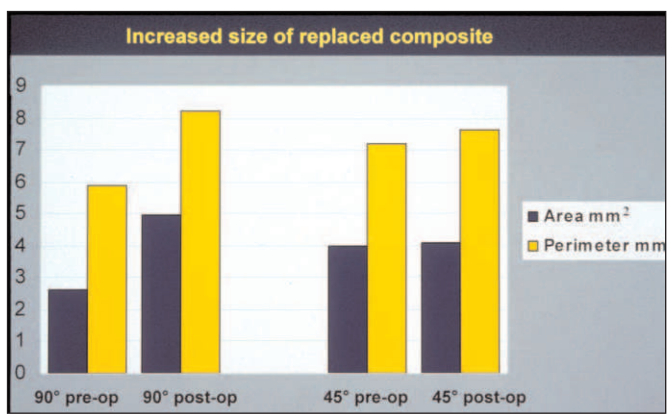

Figure 1. *Results from* in vitro *study of the increased size of cavities after replacement of composite restorations with a 90° pre- and post-operative cavosurface margin and restorations with a 45° beveled cavosurface margins. Note that a significantly increased size of the cavity occurred, expressed in mm² area and in cavity periphery expressed in mm, as a result of restoration replacement with a 90° cavosurface margin. No significant increase occurred if the cavity margin had been beveled 45°, the reason being that the beveling process already had extended the cavity margin. (Graph is based on data from Gordan, 2001).*

Figure 2. *Note the gingival marginal staining of the Class V composite restoration diagnosed as secondary caries (arrow). The lesion is localized and the remaining major part of the restoration is considered clinically acceptable.*

Figure 3. *Ditched margins on the occlusal surface of an amalgam restoration in a premolar. The ditching on the buccal aspect may be left untreated or refurbished by refinishing the margin. The lingual ditched margin may either be sealed with a resin based material or repaired with amalgam after removal of some of the restoration, as outlined by the red dotted line, to ascertain that the defect does not extend to the pulpal floor. (Courtesy of Dr Fabio Toffenetti)*

Figure 4. *An "exploratory" cavity preparation to access the extent of the stained margin of the composite margin shown in Figure 2. Since the defect was localized and limited, the small preparation is ready to be filled with a composite resin using a conventional technique, that is, the restoration was repaired rather than replaced in order to save tooth tissue.*

tooth-restoration interface and its conceived importance for the development of secondary caries (Kidd 1976, 1989). Based on the evidence available, it is unlikely that leakage at the tooth/restoration interface results in the development of caries lesions (Özer, 1997; Mjör & Toffenetti, 2000). In fact, secondary caries are basically similar to primary caries and, consequently, should be diagnosed using the same criteria for primary caries. These criteria include softening of the involved tissues and discoloration that is light yellow/orange, with a wet appearance for active caries and dark brown and dry for an arrested lesion. Per definition, secondary caries is always located adjacent to a restoration, that is, it is the location that gives the defect its name. It should be noted that a stained margin of a tooth-colored restoration should only be diagnosed as having secondary caries provided it also fulfills the other criteria for caries diagnosis.

It is essential to recognize that secondary caries does not develop along the restoration-tooth interface and progress towards the pulpal floor of the restoration, except in situations where the crevice between the tooth and the restoration is so large that food impaction may occur, that is, in situations of "macroleakage." Crevices exceeding 250 µm (Özer, 1997) or 400 µm (Kidd & others, 1995) have been indicated to be correlated to the development of secondary caries lesions. "Microleakage" on the other hand has not been shown to correlate with the development of secondary caries. In fact, no correlation appears to exist between narrow crevices and the presence of secondary caries (Merrett & Elderton, 1984; Söderholm, Antonson & Fishlschweiger, 1989; Kidd & O'Hara, 1990; Özer, 1997; Pimenta, Navarro & Consolaro, 1995). Two other *in vitro* investigations have indicated that a correlation exists between the presence of a crevice and secondary caries (Jørgensen & Wakumoto, 1968; Goldberg & others, 1981). However, this correlation could only be established in certain locations, provided the crevice was larger than 35-50 µm. Since the lesions diagnosed were limited to pits and fissures, it is possible that remaining caries was present when the restoration was inserted.

If uncertainty exists regarding the extent of the lesion or stain, enough of the restorative material should be removed to make a firm diagnosis (Figure 3). This approach rarely results in the need for removal of the entire restoration (Mjör & Toffenetti, 2000).

The gingival location of secondary caries on molars and premolars sometimes makes access difficult for localized removal of the lesion or of the stain present, but on anterior teeth, a buccal or lingual approach is possible to reach the interproximal surface. On the rare occasions when secondary caries develops occlusally (Mjör, 1985), access can easily be obtained and some of the restorative material adjacent to the defect may be removed to determine the extent of the lesion. If localized and limited in extent, it may be repaired by insert-

Figure 5. *Note the mesial and distal stained margin of the Class V composite restoration on the canine. The distal margin was diagnosed as possibly having secondary caries.*

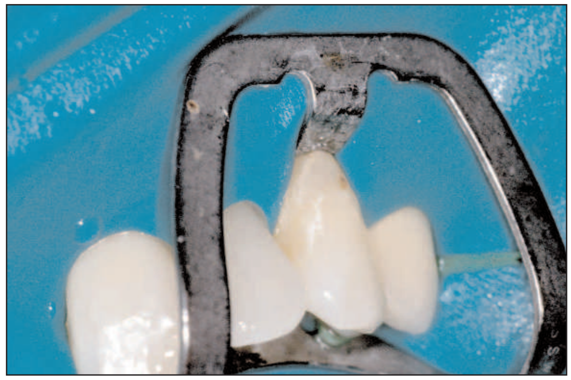

Figure 6. *The mesial stain on the Class V restoration shown in Figure 5 was removed and the suspected secondary caries lesion on the distal aspect was attempted refinishing in the same manner.*

Figure 7. *The distal defect shown on the Class V restoration in Figure 5 was refinished using a fine diamond finishing bur, and the stain was removed.*

Figure 8. *The final result after removal of excess marginal "flash" mesially and distally on the restoration shown in Figure 5. No significant loss of tooth tissue occurred during the refurbishing of the restoration, and the restoration was clinically judged to be "as good as new."*

Figure 9. *The degree of ditching of the amalgam margins on the buccal side was considered to be clinically acceptable. The ditching on the palatal side is considered to be of a degree that could be refinished or sealed. More extensive ditching should be repaired (as shown in Figure 10).*

Figure 10. *A bur was used to explore a severely ditched margin to ascertain that no lesion extended to the pulpal floor or beyond. The "exploratory" cavity preparation was then filled by amalgam.*

ing restorative material into the "exploratory" cavity preparation. Similarly, a carious or stained margin gingivally on Class III, IV and V restorations is easily accessible and can be assessed and repaired (Figure 4).

Predisposing factors to secondary caries include interproximal overhangs. Overhangs are located gingivally and they are iatrogenic defects as a result of restorative material being placed beyond the cavosurface margin of the preparation. They may lead to periodontal complications. Interproximal areas are difficult to clean by the patient and may lead to the development of secondary caries. Even small overhangs that may be difficult to detect clinically are important to avoid because they tend to be sites for plaque accumulation that predispose to the development of secondary caries (Özer, 1997). Overhangs rarely result in replacement of restorations and are usually listed under "other" reasons for failure. If clinically accessible, they must be removed or the restoration must be replaced.

Overhangs on composite restorations may represent an additional problem, especially if the material is not properly bonded to tooth structure. Resin-based materials will also attract more cariogenic bacteria than amalgam and glass ionomer materials (Svanberg, Mjör & Ørstavik, 1990). The presence of restorative material that are visible and accessible beyond the cavosurface margin are relatively easy to diagnose and remove if they are metallic or with a color contrasting that of the tooth. However, with tooth-colored restorative materials, the identification of excess material is often difficult, especially if a thin flash of material is present. Such a flash may be dislodged and later predispose to ditching and margin discoloration. Simple refurbishing procedures may then easily remove the flash (Figures 5-8). Identification of the extent of a restoration that has an optimal color match may also pose a problem during replacement of restorations because their removal may result in excessive loss of tooth tissues (Gordan, 2000, 2001).

Submarginations may also contribute to plaque retention. If they are located interproximally and especially if they are associated with crevices, they may predispose to the development of secondary caries. Small submargination defects in self-cleansing locations may be left for monitoring. If the submargination is large and associated with a crevice, the restoration may need to be replaced or repaired after the site has been cleaned.

Marginal Fractures

Non-carious, degraded or "ditched" margins are marginal discrepancies limited to the occlusal surface of restorations. Such defects were formerly limited to amalgam restorations (Figure 9). They were reported to be the reason for replacement of about 10% of all failed amalgam restorations (Mjör, 1981; 1997), but frequencies as high as 21% have been reported (Boyd, 1989). In recent practice-based studies, they represented about 5% of all reasons for replacements of all types of directly placed restorations (Mjör & others, 2000a). When these defects are of moderate size, they can successfully be dealt with by re-finishing and polishing of the margins, that is, by refurbishing the restoration (Oleinisky & others, 1996; Cardoso, Baratieri & Ritter, 1999). Non-carious ditched or defective margins adjacent to amalgam restorations that cannot be removed by grinding and finishing may be filled in by a pit and fissure sealant, by a flowable resin material or repaired by amalgam (Figure 10). Occlusal surfaces restored with present-day resin-based composite materials show that marginal degradation also occurs on composite restorations (Mjör & others, 2000a), and they may be similarly treated. No attempts have been reported on the sealing of defective glass ionomer restorations.

Bulk Failures

Discoloration of composite restorations may be a result of inferior material quality (Mjör, 1993). If the restoration is visible, it requires resurfacing or replacement to re-establish esthetics even if the restoration *per se* has no other defect. It is important to differentiate between bulk and surface discoloration. Some drinks (for example, coffee, tea and red wine) are known to discolor teeth and restorations. Smokers may also acquire tobacco stains. Such surface stains are enhanced by poor oral hygiene. Light re-finishing of the surface by abrasive disks or strips followed by polishing may provide an acceptable result (Figures 5-9). In fact, no replacement of any restoration with the diagnosis of "discoloration" should be done without first ascertaining that the unsightly appearance may be removed or improved by simple refurbishing procedures.

Bulk fracture, where a part of the restoration is loose or dislodged, may also be repaired, but it is first important to analyze the reason for the fracture. Provided the occlusal part of a Class II restoration is acceptable, and the reason for the bulk fracture can be established and handled satisfactorily, for example, by removal of caries on the gingival floor, a slot type of preparation with retention may be inserted. Cusp fractures usually require replacement by a bonded or complex restoration with pins, or by indirect restorations. Small enamel fractures may be dealt with by refurbishing/polishing or repair with resin-based material.

Restorations that result in inadequate proximal contact are examples of bulk incongruities that usually require replacement of the entire restoration. If the proximal area of a cavity preparation is wide, it is difficult to establish an optimal relationship to the neighboring surface, and an indirectly prepared restoration may be required. As an alternative treatment, a cavity preparation within the existing restoration may be attempted to establish contact with the adjacent tooth. Mechanical retention must then be created within the existing restoration. The advantage of using such an approach is that the repair will not increase the size of the original cavity preparation.

Longevity of Restorations

So-called permanent restorations are by no means permanent in the true sense of the term. In fact, the median age of replaced amalgam restorations in permanent teeth of adults treated in general dental practice is about 10-12 years, while some types of restorations, for example, those using glass ionomer materials, are replaced at a median age of 3-4 years (Mjör, 1997; Mjör, Dahl & Moorhead, 2000). Composite restorations are replaced at a median age of 7-8 years, and marked improvements in their longevity have been recorded during the last 10-20 years. During this time, resin-based composite materials became an all-round material, including their use in stress-bearing areas. Indirect restorations generally last longer, notably cast gold restorations that have been reported to have a median age at the time of replacement of 18-20 years (Mjör & Medina, 1993; Nordbø & Lyngstadaas, 1993; Jokstad, Mjör & Qvist, 1994).

Many factors affect the longevity of restorations, for example, whether the primary or the permanent dentition is treated, and for permanent teeth, the age of the patient (Qvist, Qvist & Mjör, 1991a,b; Mjör & others, 2000b). The method of payment for the treatment is important (Mjör & others, 2000b; Burke & others, 2002), and also the clinician's experience (Burke & others, 1999; Mjör & others, 2000b). The patients' oral hygiene should also be taken into consideration when selecting restorative materials (Burke & others, 2001). Furthermore, the clinicians' gender has an effect on the age of restorations in that female clinicians more readily replace restorations than male clinicians (Mjör &

others, 2000b). This myriad of factors is difficult or impossible to control in a scientifically sound, clinically relevant study design.

Repaired and Refurbished Restorations

The life span of restorations is important, not only for the life-long cost of restorative treatment, but also because replacement of restorations usually results in enlargement of the preparation, that is, loss of defective and intact tooth tissue. This enlargement in cavity size occurs even when amalgam restorations are replaced where the color of the restorative material can easily be distinguished from the color of the mineralized dental tissues (Elderton, 1977; Mjör & others, 1998). The difficulties in identifying the cavity margins are enhanced when tooth-colored materials are used (Gordan 2000, 2001).

The re-restoration cycle may result in tooth loss (Lutz, Krejci & Mörmann, 1987; Simonsen, 1991a). Whenever a restoration is to be inserted, whether it is in the treatment of primary caries lesions or to replace a failed restoration, it is important to assess its longevity. For young patients, a 60-year perspective should be kept in mind, (Mjör, 1992) because the average life span of individuals in most industrialized countries now exceeds 75 years.

The concept of minimal intervention in restorative dentistry is closely linked to the development of adhesive dental materials. Initially, minimal intervention was associated with the use of sealants and "preventive resin restorations" (Simonsen, 1991b). Minimal intervention is also connected to restorative procedures where the preparations do not need to be modified to create undercuts to retain the restorations.

Resin based materials are retained by some type of mechanical bonding to microscopic details present or formed as a result of acid etching or by chemical bonding between the material and the tooth substrate. Their use to seal crevices at tooth-restoration interfaces has not been assessed.

No data are available on the increased longevity of repaired and refurbished restorations, but studies on the longevity of such restorations are in progress (Gordan & Mjör, 2002). However, it has been demonstrated that finishing and polishing old restorations markedly reduces the number of restoration treatments planned for replacement (Cardoso & others, 1999). Thus, it is likely that refurbishing and repair of restorations will increase their longevity.

CONCLUSIONS

Limited and localized defects of restorations should be repaired or refurbished rather than replaced. The implication of the clinical diagnosis of secondary caries must be assessed carefully, as it is a localized defect. Provided the lesion can be accessed, it should be repaired rather than lead to replacement of the restoration. The main advantage of repair and refurbishing of defective restorations is to save tooth structure. It is also likely that repair and refurbishing will increase the longevity of restorations and in that way reduce the long-term cost of restorative treatment.

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Departments

Abstracts

The editor wishes to thank the second-year Comprehensive Dentistry residents at the Naval Postgraduate Dental School, Bethesda, Maryland, for their assistance in preparing these abstracts.

Remineralization of enamel subsurface lesions by sugar-free chewing gum containing Casein Phosphopeptide-Amorphous Calcium Phosphate. Shen P, Cai F, Nowicki A, Vincent J, Reynolds EC (2001) The Journal of Dental Research **80(12) 2066-2070.**

(School of Dental Science, The University of Melbourne, Victoria, 3000 Australia)

There is a continuous search to find products and materials that will suppress tooth demineralization while also enhancing tooth remineralization. Casein phosphopeptide-amorphous calcium phosphate (CPP-ACP) has been shown to have these qualities. In human *in situ* studies, this material buffered plaque pH by stabilizing and localizing amorphous calcium phosphate. The buffering of the plaque resulted in a depression of demineralization and enhancement of remineralization as much as 63.9 +/- 20.1%. This study demonstrated that sugar-free chewing gum is a safe and effective way to deliver CPP-ACP to the oral cavity in order to promote remineralization of enamel subsurface lesions.

Thirty subjects with no current caries activity were selected for the study. *In situ* studies were conducted with Sorbitol- or Xylitol–based gums containing differing amounts of CPP-ACP: a 3.0 g. Sorbitol-based pellet gum with 0.0 mg or 18.8 mg of CPP-ACP added to the pellet; a 1.9 g Sorbitol-based slab gum with 0.0 mg, 0.19 mg, 18.8 mg, or 56.4 mg of CPP-ACP added to the slab; and a 3.0 g Xylitol-based pellet gum with 0.0 mg, 10.0 mg or 18.8 mg of CPP-ACP added to the pellet. Each subject was given one type of gum and was asked to chew it for 20 minutes four times daily for 14 days while wearing an intra-oral palatal appliance which contained six enamel slabs. Each enamel slab had been demineralized so that there was an enamel subsurface lesion present. The slabs were then cut in half, with one half placed in the appliance, while the other half was retained for comparison after the treatment. After 20 minutes of gum the chewing, the appliance was kept in the mouth for an additional 20 more minutes, then placed in sealed moist plastic bags at room temperature until the gum was chewed again. After the 14-day treatment period, the enamel slabs from the appliance were placed next to their demineralized control and subjected to microradiography and microdensitometric image analysis to determine the amount of remineralization that had occurred. For each study, the subjects were asked to wait at least one week. They were then randomly given another gum to use for 14 days with analysis of the enamel slabs being completed as before. For a no-treatment control group, each subject was asked to hold the appliance in their mouth for 40 minutes four times daily without chewing the gum. The data was statistically analyzed by a one-way ANOVA and the Tukey *a posteriori* multiple comparison.

The results revealed no significant difference between sorbitol-based or xylitol-based gums with regard to their ability to remineralize subsurface enamel lesions. However, the addition of CPP-ACP in doses of 10.0 mg, 18.8 mg and 56.4 mg to either of these gums produced a significant increase in enamel remineralization with a 63%, 102% and 152% average increase, respectively. The addition of 0.19 mg of CPP-ACP resulted in a 9% increase in remineralization. The results of this study show that CPP-ACP can lead to enhanced remineralization rates when it is incorporated into a sorbitol or xylitol-based chewing gum.

Clinical evaluation of all-ceramic crowns. Gemalmaz D & Ergin S (2002) The Journal of Prosthetic Dentistry **87(2) 189-196.**

(Faculty of Dentistry, Marmara University, Istanbul, Turkey)

This study evaluated the clinical performance of IPS Empress crowns luted with a resin cement and compared the effects of two dentin adhesives used for cementation.

Thirty-seven IPS Empress crowns were placed in 20 patients. Two crowns were placed due to primary caries, five were replaced as a result of defective amalgam or composite restorations, one restored a fractured tooth and 29 replaced existing crowns due to secondary caries, fracture or esthetic inadequacy. Eighteen of the restored teeth were non-vital. Of the 18, 14 were restored with prefabricated screw shaped posts and resin composite cores.

The preparation design consisted of a circumferential shoulder with rounded internal line angles. The width of the shoulder ranged from 1.2 to 1.5 mm, with occlusal reduction being 1.5 mm (anteriors) and 2.0 mm (posteriors).The location of the crown margins was recorded before cementation and at recall appointments. Fifty-five percent of the crown margins were located subgingivally, 25% were located at the gingival margin and 20% were located supragingivally.

Complete arch impressions were made with a silicone impression material and irreversible hydrocolloid impressions were made of the opposing arch. The preparations were restored with provisional crowns until the delivery appointment.

Prior to cementation, the internal surfaces of the IPS Empress crowns were etched with 5% hydrofluoric acid for two minutes, then silanated with Monobond-S for 60 seconds. The tooth preparations were pumiced and etched with 37% phosphoric acid gel for 30 seconds.

Two different dentin adhesives were used. In 20 preparations, the surfaces were primed with Syntac Classic dentin adhesive. In 17 preparations, the tooth surfaces were primed with Syntac Single Component. A bonding agent (Heliobond) was applied to the preparations and the internal surface of the crowns and were air thinned. The crowns were luted with Variolink II low-viscosity resin cement.

The restorations were evaluated for 12 to 41 months with a mean of 24.56 months. The crowns were evaluated for margin integrity, anatomic form, color and surface character. Plaque and gingival index scores were recorded for the ceramic restorations and corresponding surfaces of control teeth.

Of the 37 IPS Empress crowns evaluated, 94.6% were rated satisfactory at the end of the mean evaluation period. One crown failed due to fracture 13 months after placement. There was no significant difference between the two dentin adhesives in regard to the failure rates (p=.7907, log rank test). Plaque index scores indicated that significantly less plaque was associated with IPS Empress crown surfaces compared to the non-restored control surfaces (p<.05). Similar gingival index scores were observed for crowns with margins at or above the gingival margin and the control teeth. Bleeding on probing was significantly higher for the IPS Empress surfaces than the controls when crown margins were placed subgingivally (p<.05).

The use of magnification in a preventive approach to caries detection Forgie A, Pine C & Pitts N (2002) Quintessence International **33(1) 13-16.**

(Dundee Dental Hospital and School, Dundee, Scotland)

Studies have shown that unaided visual diagnosis detects fewer than 50% of carious lesions on occlusal surfaces and even fewer on proximal surfaces. Although bitewing radiographs and fiber-optic transillumination can improve unaided vision, early detection of carious lesions continues to be problematic. An accessible and commonly advocated aid to diagnosis is the use of magnification. This study investigated the use of low-powered magnification (x3.25) to detect occlusal and proximal carious lesions.

Five mouth models were manufactured using extracted, unrestored, human permanent molars, premolars and canines. Seven dentists examined the teeth twice (at least five weeks apart), the first time with unaided vision and the second with magnification. All seven clinicians participated in a repeat examination five weeks later to assess reproducibility. The examinations were performed in a manner that closely replicated the clinical situation. An overhead portable dental light was used in conjunction with a three-in-one syringe with air only, two mirrors and a periodontal probe. No forceful probing was permitted. Magnification was achieved with x3.25 optic loupes mounted in plain eyeglasses. Carious lesions were recorded, and the time taken for each examination. After the examinations were performed, the teeth were removed from the mouth models and sectioned in a mesiodistal direction to allow histological diagnosis of each surface. Lesions were classified as enamel or dentinal and sensitivity, specificity and positive predictive values were calculated for diagnosis with and without magnification.

A total of 138 carious lesions were detected among the 80 teeth following their sectioning and histological analysis. There was a statistically significant difference demonstrated between the sensitivity of unaided vision and that of x3.25 magnification. Magnification detected on average three extra carious lesions per mouth model. The magnification did not appear to significantly alter the specificity of diagnosis compared to unaided vision. There were high positive predictive values (0.90) for both unaided vision and diagnosis with x3.25 magnification. Although magnification was an improvement over unaided vision, it still underestimated the number of caries lesions present. Magnification had no effect or actually decreased the length of time needed to perform dental examinations.

The findings in this study confirm that the current technique for caries detection is less than ideal and needs to be improved. Due to the increased emphasis on preventive dentistry and minimal intervention, caries detection and caries risk assessment play an important role in clinical diagnosis and treatment planning. Visual examination alone does not suffice, and it was determined that the use of low-powered magnification significantly improved the accuracy of diagnosis and can be recommended for caries detection.

A clinical, microbiologic, and radiographic study of deep caries lesions after incomplete caries removal Maltz M, Oliveira EF, Fontanella V & Bianchi R (2002) Quintessence International **33 151-159.**

(Federal University of Rio Grande do Sul, Faculty of Odontology, Porto Alegre Rio Grande do Sul, Brazil)

This seven month *in vivo* study described a method of arresting the progression of large carious lesions.

Thirty-two vital teeth were studied. Seventeen had occlusal caries only and three had approximal caries only. The remaining 12 teeth had caries in two or more surfaces. Patients ranged in age from 12 to 23. All the teeth had large carious lesions that would likely result in pulpal exposure if all carious dentin was immediately removed. All caries was removed from the tooth preparation outline. In all teeth, soft and wet carious dentin was left to cover the pulp. Dycal was placed over the caries, and the tooth was restored with IRM. After six-to-seven months, the Dycal and IRM were removed and the teeth were restored using a light-cured resin composite. The teeth were evaluated at the time of initial partial caries removal and then After six-to-seven months later. The evaluated characteristics included dentin consistency, microbial content, radiographic density and color.

After six-to-seven months, the lesions consistently showed signs of arrested caries. All dentin was dry and had significant reductions in viable bacteria. The dentin was hard in 80.00% of the cases, leathery in 16.67% of the cases and soft in 3.33% of the cases. Radiodensity of the carious lesions had also significantly increased. Furthermore, the color of the dentin darkened, perhaps due to degenerating bacteria. Thirty teeth completed the study. Two teeth were excluded, one due to pulpal exposure at the time of the initial caries removal and the other because it developed pulpal necrosis.

The results of this study showed that carious progression was arrested when the carious lesions were isolated from the oral environment.

A comparison of strengths of five core and post-and-core systems Möllersten L, Lockowandt P & Lindén LA (2002) Quintessence International **33(2) 140-148.**

(This study was conducted in the Karolinska Institute, Huddinge, Sweden Department of Dental Biomaterial Science)

Severely worn or broken down teeth often require a core or post and core substructure to support the final restoration. Gold alloys have traditionally been used as substructures to restore vital and non-vital teeth. Alloy-reinforced glass ionomer cement and resin composite are also frequently used. The most common problems associated with crown substructures include fractures, loosening of the post and core and microleakage. Questions arise concerning the strength of different cores and post and core systems and whether a stronger restoration is achieved through intentional endodontic treatment followed with a cast post and core versus the placement of a pin-retained core on vital tooth structure. This study compared the strength of alloy-reinforced glass ionomer cement cores with parapulpal threaded retention pins, resin composite cores with parapulpal threaded pins and cast gold cores with parallel parapulpal pins on vital teeth; and cast gold alloy post and cores and Composiposts with resin cores in non-vital teeth.

Forty-five teeth, 15 molars and 30 premolars were used in this study. The teeth were ground flat to expose the dentin and to simulate teeth with short clinical crowns. Ten molars were prepared with four-threaded max pins each and mounted in plastic tube matrix 8 mm high. Five were restored with Ketac-silver and five with posterior resin composite (Ariston). Thirty-five percent phosphoric acid and Ariston light cure bonding agent was used prior to composite core fabrication. Gold cores in vital teeth were fabricated in five molars and 10 premolars by using four No-Ox pins in each tooth and an 8 mm core wax pattern. The cores were cemented with zinc phosphate cement. Twenty premolars were endodontically prepared and filled with resin chloroform and gutta-percha. They were prepared to receive post and core restorations. Ten received a cast gold post and core and 10 received a Composipost with a polyurethane-acrylic autopolymerizing resin with short filler fiber core. All the specimens were tested applying loading forces perpendicular to the long axis of the tooth with a Zwick universal material-testing machine until failure was evident. One-way analysis of variance with a covariate was used to examine the differences in geometric mean strength. In case of overall significant result, post hoc comparisons were performed according to Turkey's honest significance difference.

The failure mode in the glass ionomer and the resin composite cores occurred within the material surrounding the pins. The gold cores with parallel pin retention and gold post and cores failed at the zinc phosphate cement seal. In the Composipost group, the failure occurred during the fracture of the acrylic resin cement seal. On the strength test, the gold alloy core with parallel pins and composite cores with threaded pins had higher values than did the glass ionomer cores with threaded pins. No statistical difference could be demonstrated between the cast gold post and the Composipost groups. Using a glass ionomer core with threaded pins is not recommended as a build-up system due to its inferior fracture resistance. This study indicated that the cast core with parallel pins, cast post and core and Composipost are equivalent in strength. The use of a gold core in combination with parallel parapulpal pins demonstrated high resistance values in vital teeth, and it seems justified to consider a vital core solution rather than endodontic treatment.

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The University of Texas Health Science Center at Houston Dental Branch seeks applicants for a full-time, tenure or clinical educator track position in the Department of Restorative Dentistry and Biomaterials at the assistant or associate professor level. Applicants must have a DDS/DMD degree with prior teaching and/or private practice experience. Advanced training in Operative Dentistry, Prosthodontics or GPR/AEGD certification is preferred. Responsibilities include clinical and preclinical teaching to undergraduate and graduate dental students, research and service. The position is available September 1, 2002. Academic rank and salary are commensurate with qualifications and experience. The University of Texas Health Science Center at Houston is an equal opportunity employer and a non-smoking environment. Women and minorities are encouraged to apply. Send a letter of application, a curriculum vitae and a list of three references to: Dr Peter Triolo, University of Texas Dental Branch, Department of Restorative Dentistry and Biomaterials, 6516 M D Anderson Blvd, Suite 493, Houston, TX 77030.

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If an abstract, based on the research and acknowledging support from the Academy of Operative Dentistry, is accepted for presentation at the IADR/AADR meeting in 2003, additional travel funds not exceeding $1,000 will be made available to the recipient.

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Research Committee
c/o Dr Ivar A Mjör, Chairman
UFCD, Box 100415
Gainesville, FL 32610

Applications may also be submitted by e-mail to: imjor@dental.ufl.edu followed by one signed original mailed to the above address. Award recipients will be announced during the Annual Meeting of the Academy of Operative Dentistry, February 26-28, 2003.

32nd Annual Meeting of the Academy of Operative Dentistry
26-28 February 2003, Fairmont Hotel, Chicago, IL

The Academy of Operative Dentistry's 32nd Annual Meeting once again offers an incredible group of essayists, an outstanding table clinic session and a wonderful social program.

SCIENTIFIC SESSION: Thursday begins with Dr Sasha Jovanovic speaking on "Optimal Esthetics with Implant Dentistry," followed by Dr Jimmy Eubanks discussing "Occlusion and Restoration Design." This year's Buonocore Memorial Lecturer is Dr Bart Van Meerbeek, who will present "Bonding to Tooth Tissue: Current Status and Challenges of the Future." Thursday afternoon features Dr William "Buddy" Mopper's presentation on "The Efficacy of Veneering with Direct Bonding" and Dr Shane White explains the new model of enamel microstructure in "Enamel and DEJ: Structure, Function and Why We Need to Preserve It." Dr Richard D Tucker leads off on Friday morning with "Cast Gold Restorations with Integral Pins" and Dr Edward McLaren follows with "Ceramic Systems: Material Considerations and Selection Criteria." Finally, Dr Bruce W Small wraps up the essay sessions with an evidence-based protocol for restorative dental practice titled "Putting it All Together." Friday afternoon's exceptional group of table clinics organized by Dr Richard Kloehn will complete the 2003 Scientific Session.

Information on the Companion Program and Gala Reception has not been finalized but will appear in the next issue.

Please don't miss this fantastic opportunity for education, information exchange and fun. See you in Chicago in February! For more meeting information, please contact Dr Gregory Smith, PO Box 14996, Gainesville, FL 32604-2996; fax (352) 371-4882.

American Academy of Gold Foil Operators 50th Anniversary Meeting

October 9-12, 2002, Halifax, Nova Scotia

Please join us for a very special meeting honoring the 50th anniversary of the Academy. The scientific program consists of an outstanding essay series and two half-day clinical demonstration sessions hosted by Dalhousie University School of Dentistry. Social activities will include tours of Nova Scotia's scenic beauty, casinos, a lobster dinner with entertainment by Celtic musicians and our Gala Banquet on Saturday night. Come to Nova Scotia for education, celebration and fun. For further information, contact Academy Secretary, Dr Ron Harris.

Phone: (317) 867-0414; e-mail: piperon@earthlink.net.

Operative Dentistry Home Page

We hope all our readers will take advantage of the information available by accessing our Internet home page. Our address is: **http://www.jopdent.org/**

The home page contains a search engine and buttons that, hopefully, will lead you to answers to any questions you may have related to Operative Dentistry. These are:

Journal: leads to information on the Editorial Staff and Editorial Board; a complete index of journal volumes; a compilation of direct gold references; highlights of the current, next, and future issues, as well as a more detailed look at published Editorials and Clinical Pearls.

Subscribe: leads to complete information on subscription rates; purchasing back issues, reprints, and bound volumes; and subscription and change of address forms.

Affiliates: provides links to the American Academy of Gold Foil Operators, the Academy of Operative Dentistry, the AADS-Operative Section, and our Corporate Sponsors. In addition, membership applications for the journal's parent academies are available for downloading.

News: announcements of interest to our readers, including meeting information, advertised faculty positions, and upcoming CE courses.

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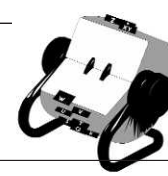

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Instructions to Contributors

Correspondence

Send manuscripts and correspondence regarding manuscripts to Dr Michael A Cochran, Editor, *Operative Dentistry*, Indiana University School of Dentistry, Room S411, 1121 W Michigan St, Indpls, IN 46202-5186; phone (317) 278-4800; fax (317) 278-4900; e-mail: editor@jopdent.org; URL: http://www.jopdent.org/.

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All material submitted for publication must be submitted exclusively to *Operative Dentistry*. Manuscripts not following the form outlined below may be returned for correction and resubmission.

Manuscripts

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❒ Submit a computer disk and identify the operating system (Macintosh or IBM-compatible) and the word processing program used.

❒ Identify the corresponding author and provide a complete address, fax number and e-mail address.

❒ Supply complete names, degrees, titles and affiliations for all authors (include addresses that are different from the corresponding author's).

❒ Proprietary names of equipment, instruments and materials should be followed in parenthesis by the name and address, of the source or manufacturer.

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